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HEAD TRACKING SYSTEM WITH LPC1758

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Declaration

„I confirm that this thesis is entirely my own work. All sources and quotations have been fully acknowledged in the appropriate places with adequate footnotes and citations. Quotations have been properly acknowledged and marked with appropriate punctuation. The works consulted are listed in the bibliography. This paper has not been submitted to another examination panel in the same or a similar form, and has not been published. I declare that the present paper is identical to the version uploaded."

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Resumen

En este trabajo se presenta el diseño de un sistema head-tracking que puede ser utilizado como ratón de ordenador para personas con discapacidad. El sistema se compone de un microcontrolador LPC1758 integrado en la plataforma eStick2 desarrollada por la FH Technikum Wien, además de una cámara PAC7001 y un conjunto de 4 LEDs dispuestos en un prisma rectangular.

El proyecto describe en detalle el proceso de desarrollo del software, describiendo los distintos pasos tomados, programas secundarios realizados para comprobar el funcionamiento de las distintas conexiones necesarias, como USB o UART, y los distintos problemas aparecidos así como el protocolo de activación de la cámara. Se ofrecen también los distintos resultados de las mediciones realizadas para el sistema head tracking y conclusiones al respecto de esas mediciones.

En conclusión, en este trabajo se analizan las limitaciones de la configuración seleccionada y se cuestiona su idoneidad para la función deseada.

Abstract

The intention is to create a program that controls a head tracking system for disabled people. The system is composed by a PAC7001 camera, the LPC1758 microcontroller integrated in to the eStick2 platform and a set of infrared LEDs. To attain this objective, UART and USB connections are used, and the POSIT algorithm also has a relevant role in the final achievement of the software. In this paper the process of doing the software of the head tracking system and the different programs built to finally obtain this software are described. These programs are used to understand how the USB or the UART connection worked, to check how the pointer of the mouse is moved or to see the data captured by the PAC7001 camera and how these data had to be treated. The different problems that appeared during the programming are described, how they have been solved and also the final result. Finally it is discovered that it was no possible to build a program that worked properly with the components used and some advices for future improvements are given.

Keywords: Head tracking system, PAC7001, LPC1758

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1 Objective of the project

The aim of this project is to build a low-cost head tracking system and mainly to make a program to govern that system, with the best possible efficiency and capability to control the mouse pointer of the compute. It must be appropriate for people with motion disabilities, especially for those with spinal damage.

The scheme of the head tracking is composed of a microcontroller, a camera and a small simple system of four infrared LEDs forming a rectangular prism, all properly connected to a computer.

The camera, which is attached on the user's head, identifies the position of the LED system, which is placed on top of the computer screen. This information is sent to the microcontroller, the created software housed in it estimates the position that the camera is pointing at and therefore which part of the screen the user is looking at. This then translates it into movement of the mouse pointer and sends it to the computer, moving the pointer to the estimated point of the screen.

2 Components of the project

2.1 LPC1758

As it is described in the NXP LPC17xx User Manual¹ that can be found in the appendix A (p. 3), “the LPC17xx is an ARM Cortex-M3 based microcontroller for embedded applications featuring a high level of integration and low power consumption. The ARM Cortex-M3 is a next generation core that offers system enhancements such as improved debug features and a high level of support block integration”.

Continuing with the description of the User Manual, “the LPC1758 operates at CPU frequencies up to 100MHz. The ARM Cortex-M3 CPU incorporates a 3-stage pipeline and uses Harvard architecture with separate local instruction and data buses as well as a third bus for peripherals. Also includes an internal prefetch unit that supports speculative branching”.

The peripheral complement of the LPC1758 includes up to 512kB of flash memory, up to 64kB of data memory, Ethernet MAC, a USB interface that can be configured as either Host, Device or OTG, 8-channel general purpose DMA controller, 4 UARTs, 2 CAN channels, 2 SSP controllers, SPI interface, 2 I²C-bus interfaces, 2-input plus 2-output I²S-bus interface, 6 channel 12-bit ADC, 10-bit DAC, motor control PWN, Quadrature Encoder interface, 4 general purpose timers, 6-output general purpose PWN, ultra-low power Real-Time Clock (RTC) with separate battery supply, and up to 52 general purpose I/O pins.

In the case of the used system, the LPC1758 is integrated in the eStick2. The eStick2, presented in Figure 1, is a low-cost powerful embedded computing platform and has been developed in the context of the MA23 funded project ‘Embedded Platforms’ at the FH Technikum Wien.

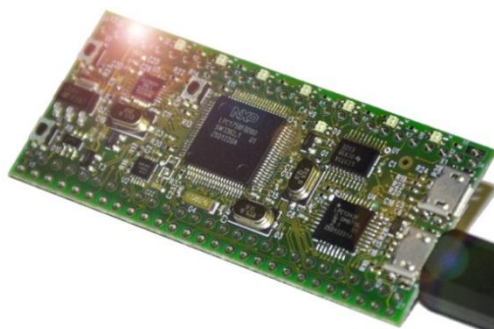


Figure 1: eStick2 (Source: [1])²

¹ http://www.nxp.com/documents/user_manual/UM10360.pdf

² <https://cis.technikum-wien.at/documents/bel/3/ess/semesterplan/estick2/estick2.html>

The eStick2 provides a compatible interface to the LPCXPRESSO Base Board from Embedded Artist. Power is supplied to the eStick2 board via a standard micro-USB cable as used by almost all smartphones nowadays.

2.2 LPCXPRESSO Base Board

The LPCXpresso Base Board is a useful tool when prototyping work is needed or to learn more about a certain microcontroller. It works with the LPCXpresso boards and with the mbed module and it is also compatible with the eStick2 used in this research.

The LPCXpresso Base Board it is shown in Figure 2 and contains a lot of devices which can be used to make different programs for the microcontroller that is wanted to be integrated in the board. So it is possible to get started with experiments and with the operation of a microcontroller. Different standards of communication can be learnt to manage and use this board and it is the way used in the study to start working with the LPC1343 and the LPC1758.

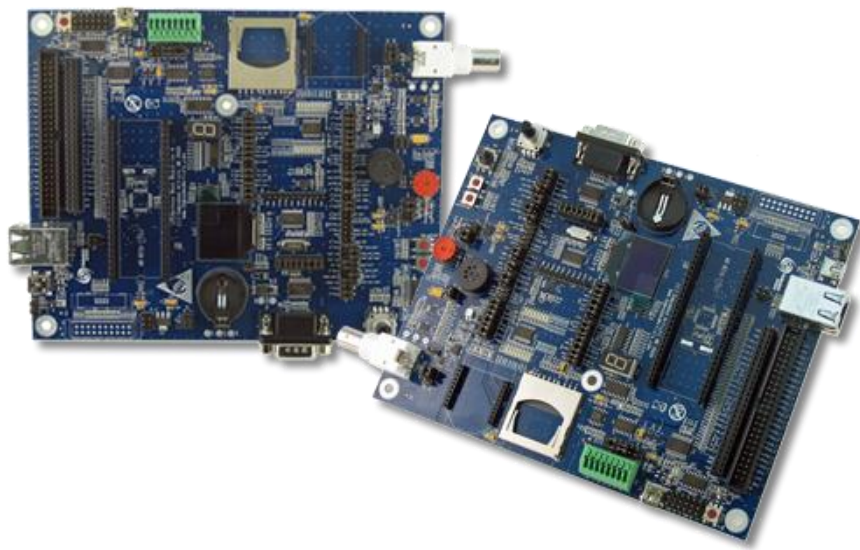


Figure 2: LPCXpresso BaseBoard (Source: [2])³

2.3 PAC7001 camera

The camera used for the head tracking systems is a PAC7001CS from the PixArt Imaging Inc. Company. According to the datasheet, it is an object tracking sensor (MOT sensor), a motion tracing application-specific integrated circuit (ASIC) with high quality CMOS image sensor, DSP and UART protocol. This sensor can track up to four objects

³ http://www.embeddedartists.com/products/lpcxpresso/xpr_base.php

smartly with sub-pixel accuracy and output the objects features, like center coordinates or the object size. These output features of the objects can be transferred to an external processor, in this case to the LPC1758 microcontroller, through UART interface.

The specifications of the sensor are in the datasheet and are exhibited in Table1.

Specification	Values
Power Supply	3~5V
Array Elements	128 x 96
Optical Format	1/10"
Pixel Size	11µm x 11µm
System Clock	27MHz
PGA Gain	16X(24dB)
Frame Rate	10~200fps
Scan Mode	Progressive
Output Interface	UART
UART Baud Rate	Max Osc / 16
Object center coordinate resolution	Max 1024*768
Package	CSP

Table 1: Specifications of the PAC7001

The PAC7001CS can be programmed by setting internal registers via UART and doing that different parameters can be changed, such as frame rate, exposure control, object center resolution, UART speed, etc. Table 2 lists the internal registers of the camera:

Register Number	Name	Default	Allowable Range	Description
0x00	Gain1 (1byte)	0	0~15	Sensor Front Gain
0x01	Gain2 (1byte)	0	0~31	Sensor Global Gain
0x02	Sensor Update Flag	0	0,1	1: For Sensor Register Update
0x03	LPF (1byte)	110	110~255	Line per Frame
0x04	Ny (1byte)	1	<LPF	Ny
0x05	IW (2bytes)	640	Max 1024	Image Width
0x06	IH (2bytes)	480	Max 768	Image Height

Register Number	Name	Default	Allowable Range	Description
0x07	Threshold	136	0,1	Bit7:0=Manual,1=Auto
	Mode		0	Bit6:0
	-		0	Bit5:0
	-		0,1	Bit4:0=Normal,1=Power down
	Power Down Mode		1	Bit3:1
	-		0-7	Bit[2:0]: Dummy data in object feature data
0x08	Dummy byte number [2:0]			
0x08	Threshold (1byte)	40	0~255	Object Threshold
0x0E	Object Assignment Mode	0	0	0:No Assignment Mode
0x0F	Feature Option Enable Flag	0x7F	0x00~0xFF	Bit Definition: 0=Disable, 1=Enable Bit7: Frame header Bit6:Object aspect ratio Bit5: Object orientation Bit4: Object size Bit3: Object border Y Bit2: Object Border X Bit1: Object center Y Bit0: Object center X
0x10	Tracking Object Number	1	1~4	Tracking Object Number
0x11	Baud Rate	0	0~8	System clock = 27MHz 0: 27M/1407=19200bps 1:27M/256 2:27M/16 3:27M/703=38400bps 4:27M/469=57600bps 5:27M/234=115200bps 6:27M/117=230400bps 7:27M/59=460800bps 8:27M/29=921600bps

Register Number	Name	Default	Allowable Range	Description
0x16	SRC	0	-	Skip Report Count
0x18	Aspect Threshold	0x34	0x00~0xFF	Bit[7:4]:Orientation Ratio Bit[3:0]: Reserve
0x1A	YLB	50	0~255	Frame Brightness Low Bound
0x1B	OALB	8	0~255	Object Area Low Bound
0x1E	Np_H	0	0~3	PXCLK=SYSCLK/2Np; Np=(Np_H,Np_L)
0x1F	Np_L	3	3~255	PXCLK=SYSCLK/2Np; Np=(Np_H,Np_L)

Table 2: Registers of the PAC7001

Gain1 is analog front gain, Gain2 is global gain, is preferable increase Gain1 first for better SNR. The Gain equation is $G1 = (16 + \text{Gain1})/6$, Gain1 = 0~15; $G2 = (10 + \text{gain2})/8$, Gain2= 0~31. Total Gain (dB) = $20\log G1 + 20\log G2$. The Exposure Line is equal to $(LPF + 1) - Ny$ and the Exposure time equation is $(187*(LPF + 1 - Ny)*2*Np)/\text{SystemClock}$. Frame per second (fps) is $\text{SystemClock}/(187*(LPF + 1)*2*Np)$. Then the IW value must be $128*(\text{integral})$, for example 128, 256... and IH must be $96*(\text{integral})$ as 96, 192... and the IW:IH ratio must be 4:3. About the OLAB, if the camera detected an object but his size is under OLAB defined, then PAC7001 will ignore this object and will not output its features.

So these are the registers that have to be configured in the sensor to make it work as it is wanted, but to write in this register first it is needed to send the value 0x10 to set them, and then the register number can be selected and set with the proper value. Once the setting of the register is finalized, the sensor has to be switched to "Operation mode", by sending the 0x8D value to the camera, to start the output of the objects features. These outputs features depend on the 0x0F register, but the normal outputs it is first the header and then the list of the features of the objects. The header, which is of 4 bytes, is:

0xFF → 0x00 → 0xFF → 0xFF

And the normal selected features and their order is:

Flag Byte (1 byte) + Object Flag Byte (1 byte) + X (High Byte) + X (Low Byte) + Y (High Byte) + Y (Low Byte) + EOB (1 byte)

This scheme is repeated with the features of each object. If the sensor is programmed for detecting only one object, the same scheme will be repeated four times but if the sensor can detect 4 different objects, there will be four different schemes, preceded by the header. Below are the means or the values that have to be received in each bit of the parameters Flag Byte, Object Flag Byte and EOB:

❖ Flag Byte

- Bit 7: always 1
- Bit [5:6]: Condition
 - 0: Invalid → Object is not found
 - 1: Trace → Trace is O
 - 2: Reserved
 - 3: Reserved
- Bit [0:4]: Frame Number

❖ Object Flag Byte

- Bit 7: 0
- Bit [4:6]: Reserved
- Bit [2:3]:
 - 0: Circle object
 - 1: Bar Object
 - 2: Circle-hole Object
 - 3: Bar-hole Object
- Bit 1: Reserved
- Bit 0:
 - 0: Finish
 - 1: Not Finish

❖ EOB

- Bit 7: 0
- Bit [4:6]: Object Number
- Bit [0:3]: Checksum (Bytes XOR, then Nibbles XOR)

When it is wanted to end with the outputting of the data it is needed to get out of the “Operation mode” and go back to the “Initial Mode”, sending the value 0x8E to the camera. This “Initial mode” is the mode in which the registers are configured and is the initial mode of the camera, but to activate the camera after power on the value 0xEA needs to be sent to check the sensor. In Figure 3 it is represented the scheme of this activation of modes:

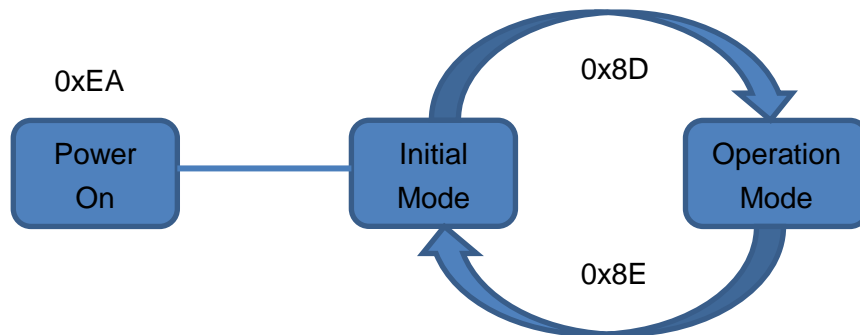


Figure 3: Scheme of the modes of the camera

2.4 Set of LEDs

The set of LEDs is the reference that it is going to be taken to move the pointer of the mouse related to the point that the camera is focusing at. The camera has to be pointing somewhere inside this set so the program can be able to move the mouse.

This set is a rectangular prism of 11x8.5x9cm with four infrared LEDs distributed in pairs, so that there are two LEDs in the front part and the other two in the back part. In the front part, there is one LED in the lower left corner and the other in the upper right corner while in the back part the LEDs are in the upper left and the lower right corner.

The set, in Figure 4, can be connected via USB to the computer to act it as power supply of the LEDs and it is also provided with a support to hold it on the screen of the computer.



Figure 4: Set of LEDs

3 State of the Art

Assistive Technology (AT) is a term that covers lots of fields related to the use of technology in the common life of people with disabilities to make it easier, to perform functions that otherwise could be difficult or impossible.

AT includes assistive, adaptive and rehabilitative technology and even the process used in selecting, locating and using them. AT technology can include mobility devices as wheelchairs, walkers or mobility scooter as well as hardware, software and peripherals that assist people with disabilities in accessing computers or different kinds of automated dispositive. All this things promote greater independence to the users, for example, people who are blind may use software that read texts on a screen with a computer-generated voice, those who have low vision can enlarge the content of a screen using a special software, deaf people may use a text telephone or users with speaking problems can employ devices that speak for them introducing a text via keyboard.

But this research is focused on disabled people with mobility problems, because the system is addressed to this kind of disability. These people have permanent or transitory difficulties moving their body, difficulties that can affect from one specific part of their body to a total paralysis. It can be caused by problems with the tone or the power of the muscles or problems with mental functions that control sequencing complex movements, the usual functioning of the central nervous system and the articular system or the muscular system, which translates in bad regulation of complex voluntary movements. The affected present a disadvantage in their locomotor system, determined by postural limitations, displacement, coordination and handling. The causes can be various: hereditary or genetic, occurred during pregnancy (amniotic), for microbial infections, by accident or trauma, and can be the origin of spinal cord injuries, traumatic brain injuries, neurological disorders, cerebral palsy, multiple sclerosis, muscular dystrophy and other diseases source of locomotor disabilities.

Now a review of different tools is going to be done. Of devices on the market destined to motor disable people but focusing on those tools dedicated to simplify the access to a computer for these people. Currently, computers have an important role in our society, and not always people with disabilities can make use of them because of their illnesses. One of the main fields in assistive technology is to resolve this problem, developing accessing gadgets to computers to this kind of users, making their lives easier and allowing them to participate in modern society. These devices are systems for alternative human computer interaction, like special keyboards, mice, pointers and other advanced tools.

3.1 Keyboards

3.1.1 Expanded Keyboard

It is an adapted USB Keyboard designed with larger keys and high contrast colors. This keyboard is removable so the user can rest his hands on it. It includes mouse buttons that can handle the pointer and make clicks as a conventional mouse. It is a keyboard created for people with motor problems or reduced visibility. Two different types of these keyboards are exposed in Figure 5.



Figure 5: Expanded keyboards (Source: [3][4])^{4 5}

3.1.2 One-handed keyboard

This kind of keyboards, like the ones in Figure 6, is designed to be handled with one hand, even some of them with only two fingers. They have the keys distributed in an accessible way to be able to reach them easily with one hand. They can also have only a few keys, less than a normal keyboard, and it is necessary to enter key combinations to write with them. There are keyboards for both hands or some of them can be programmable to select the hand to use. It is optimum to people with reduced mobility in one of the upper extremities.

⁴ http://www.ciapat.org/es/catalogo_producto/teclado-expandido

⁵ <http://www.geekets.com/2009/02/>



Figure 6: One-handed keyboards (Source:[5][6])^{6 7}

3.1.3 Ergonomic Keyboards

They have special form and distribution of the keys to facilitate the insertion of data as they adapt to the shape of our hands. It reduces wrist movement and the movement of arms, neck and shoulders. The disposition of the letters can be changed to decrease the movement of the fingers. They are available for left, right or both hands. They are also useful for people with problems or pains in the upper body. Two ergonomic keyboards are collected in Figure 7.



Figure 7: Ergonomic keyboards(Source: [7][8])^{8 9}

⁶ <http://www.tested.com/tech/280-alternative-keyboard-layouts-why-are-you-still-using-qwerty/>

⁷ <http://carlygoogles.blogspot.com.es/2011/02/has-anyone-invented-one-handed-keyboard.html>

⁸ <http://ounae.com/maltron-keyboard/>

⁹ <http://www.enablemart.com/catalogsearch/result/?q=alternative+keyboards>

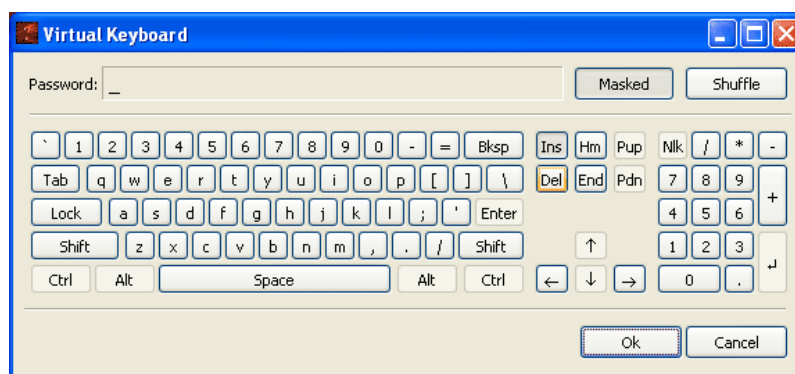
One different ergonomic keyboard it is the Orbitouch keyboard, in Figure 8. It consists of two special joysticks with eight positions. On the right joystick there are five letters, numbers or symbols in each position, each character with one color and on the left joystick there are the five colors. So when it is wanted to select a character, the joystick of the left hand is moved to the color of the character and the joystick of the right and to the position where the character is.



Figure 8: Orbitouch keyboard (Source: [9])¹⁰

3.1.4 On-screen keyboard

They are virtual keyboards on the computer which can be controlled by the common mouse or by a special adapted mouse. Most of them have words or phrases that are predicted while typing and can stock new words and register the frequency of usage of the words. Some of the software of these virtual keyboards give the option to select the position of the characters in the keyboards, which make them more accessible to the users. There are two on-screen keyboards in Figure 9.



¹⁰ <http://orbitouch.com/>

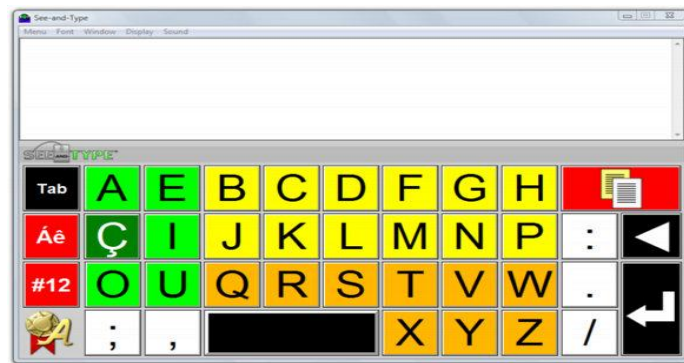


Figure 9: On-Screen keyboards (Source: [10][11])^{11 12}

3.1.5 Other types

There are lots of other types of keyboards (Figure 10) so useful to people with disabilities. There are keyboards to handle with feet, for those who cannot use their hands. They are larger than the common keyboards to reach each key without problems of space. There are also keyboards which do not look like keyboards. They have only a few keys and can be handled with one hand and the combination of these keys can generate the characters of a usual keyboard. They are suitable for people with problems moving their arms, shoulders or with back problems



¹¹<http://www.safebit.net/screenshots/safebit-disk-encryption-software-screenshot-virtual-keyboard.html>

¹²http://www.aureosoft.com/see_and_type.html



Figure 10: Different types of keyboards (Source: [12][13][14])^{13 14 15}

3.2 Mice and joysticks:

3.2.1 Ergonomic mice and joysticks

The normal design of mice and joysticks can be harmful for people with joint problems or other similar diseases. Therefore, there are lots of different forms and models for these devices making them suitable for the people with these ailments. A large variety of ergonomic mice can be found in the market, as the ones in Figure 11, so the user can select the comfortable model that reduce or solve his pain.



Figure 11: Ergonomic mice and joysticks (Source: [15][16])^{16 17}

¹³<http://www.demotix.com/news/1758185/foot-keyboard-unveiled-gajah-mada-university-disabled-users/all-media>

¹⁴<http://www.coroflot.com/erikcampbell/optical-keyboard-keyset>

¹⁵ <http://walyou.com/jellyfish-keyboard-keyset/>

¹⁶ <http://www.computer-posture.co.uk/Tennis-Elbow>

¹⁷ http://www.fentek-ind.com/zero_tension_mouse.htm#.UiCtZH8rj9M

3.2.2 Trackballs

Another device working as a mouse is the trackball. It consists in moving a ball instead of the whole dispositive of a mouse to move the pointer. Normally it has separated buttons to avoid unintentional pressing and make clicks like a normal mouse. The roll of the ball can be done with a hand or just with one finger. That reduces the movement of hand and arm to control the pointer and makes it perfect for people with wrist problems or similar ailments. Two types of trackballs are shown in Figure 12.



Figure 12: Trackballs (Source: [17][18])^{18 19}

3.2.3 Feet mice

There are also mice that can be moved with our feet. They are much appropriated and specially designed for people with disabilities of the upper limbs. There are different types of feet handled mice in the market, most of them based in two pedals system, controlling the pointer with one and the clicking with the other. A different model consists in a kind of “slipper pointer” moving around like a hand mouse and a series of buttons acting as the ones in typical mice, including a button for double click or scroll roller. There is even a mouse for the toes, a small wireless mouse with a clamp which is placed between the big toe and the second toe. The pointer is controlled moving this mouse and the left and right click can be done with the big toe and the second toe separately. This variety of feet mice is gathered in Figure 13.

¹⁸ <http://www.oucs.ox.ac.uk/enable/index.xml?ID=mice>

¹⁹ http://www.assistireland.ie/eng/Products_Directory/Computers/Hardware/Input_Devices/Mice_and_Mouse_Alternatives/Trackballs_/BIGTrack_Supermouse.html



Figure 13: Feet mice (Source: [19][20][21])^{20 21 22}

3.2.4 Special joysticks

Joysticks can substitute the mouse and normally less effort is needed to move it always in a smaller area of movement. It can be used in a lying position which is something to consider as many patients cannot sit up. Another useful type of joystick is the mouth controlled joystick (Figure 14). Is an efficient device for those people suffering paralysis below the neck. They can control the pointer moving this joystick with the tongue or the mouth, even control the clicking.



Figure 14: Special joysticks (Source: [22][23])^{23 24}

²⁰<http://www.yankodesign.com/2010/04/07/flip-flop-mouse/>

²¹http://bilila.com/foot_mouse_slipper_mouse

²² <http://www.funny-potato.com/computer-mice.html>

²³<http://www.turningpointtechnology.com/Sx/AltMice.asp>

²⁴<http://jansapansa.blogspot.com.es/>

3.2.5 Headpointers and mouthsticks

There are other tools that are less advanced that allow people with disabilities to make use of computers. These are the headpointers and mouthsticks, consisting in a stick held by the head or the mouth used to type, move the mouse or touch the screen. One example of each of these tools is exposed in Figure 15.



Figure 15: Headpointers and mouthsticks (Source: [24][25])^{25 26}

3.3 Tracking systems

Following other techniques of interaction with computers are described, based on the tracking of the user focusing on head and eye tracking.

3.3.1 Head tracking

Head tracking technology consists of a device transmitting a signal from on top of the computer monitor or the laptop and tracking a reflector placed on the user's head or on special glasses. Acting as a mouse, with a head tracking system a person can control the cursor movement with the movement of his head. Turning the head left or right, up or down, the pointer follows that movement on the screen. There are also head tracking systems in the opposite way, with reflectors placed on the screen and the transmitting gadget on the head of the users. The gadget and the reflectors can be replaced by infrared detector camera and infrared lights acting as positional signals and it works as the previous describe system. Two different devices are presented in Figure 16.

²⁵<http://www.ilcnsw.asn.au/items/6795>

²⁶<http://www.cultofmac.com/147506/dutch-inventor-creates-specialized-accessories-for-ipad-users-with-disabilities/>



Figure 16: Head tracking devices (Source: [26][27])^{27 28}

To the mouse “click” function there are different possibilities depending on which head tracking device is used. With some systems peripherals buttons can be added to act as the common mice buttons, others can interpret that, if the cursor is stationed on an icon during a predefined time, it means that the user wants to click here or making another assigned mouse function. It can be combined with blink systems that recognize the blinks of the user and translate them in mouse buttons functions depending on how it has been configured.

It is really interesting to combine this head tracking system with the on-screen keyboards previously described so the user can both control the cursor of the mouse and write only moving his head.

3.3.2 Eye tracking

Eye tracking systems work similar as the head tracking system. Eye tracking is the process of measuring the point of gaze, where the user is looking, or the movement of the eyes related to the position of the head. To use this technology to help disabled people to interact with computers, the system consists of a camera pointing to the user’s eye and a software that translates the movement of the eye, or the place of the screen where it is looking at, into movement of the mouse’s pointer. This camera is normally integrated in special glasses or other devices attached to the head, which also can have included another camera pointing to the screen to take into account the position of the head relative to it and coordinate this with the eye camera.

Some examples of eye tracking systems are gathered in Figure 17.

²⁷<http://www.slcentral.com/c/h/r/naturalpoint/trackir/>

²⁸<http://abilityhub.com/mouse/headtrack.htm>



Figure 17: Eye tracking systems (Source: [28][29])^{29 30}

This system could be used for people who have spinal cord injuries as well as those with late-stage Parkinson, muscular dystrophy and multiple sclerosis. The eyes are directly connected to the brain stem so their movement is not affected by spinal cord injuries.

As in the case of head tracking system, the mouse click function can be controlled by a blink system, much more easily since there is already a camera pointing to the eye. An also with one on-screen keyboard tool this systems is much more complete.

²⁹http://www.methoden-psychologie.de/eyetracker_1.html

³⁰http://cda.psych.uiuc.edu/matlab_class/Eyelink%20Toolbox%20Home.htm

4 Preliminary Work

The implemented low-cost head tracking system consist of a LPC1758 integrated in the eStick2, a PAC7001 camera and a set of LEDs. All of them are needed to be controlled to make them work as it is required and this role falls in the microcontroller. Since the microcontroller is the main part of the system it is very important to know how it works. For that objective, small programs were built using the LPC1758 addressing various functions and utilizing its peripherals to interface with the LPCXpresso Base Board

First of all, work began with the LPC1343, the other microcontroller integrated in the eStick2, which uses the same language (C) as the LPC1758. The LPC1343 is an ARM Cortex-M3 based microcontroller for embedded applications and has a high level of integration and low power consumption, as the LPC1758. Both microcontrollers are quite similar but the LPC1758 has more capacity than the LPC1343, meaning that more different devices can be controlled with the first than with the second microcontroller. The LPC1343 manages the dispositive integrated in the eStick2, so with the first built programs the 8 LEDs and the accelerometer of the platform can be controlled.

To start programing, first it is needed to setup an open-source tool-chain to develop software for the eStick2 so it can be accessible. This information is given in the Embedded Systems Software Design page of the FH Technikum Wien web site. The first step that has to be taken is the installation of the USB Device Driver and the Download of the CodeSourcery C Compiler for Arm. Then the OpenOCD has to be downloaded and installed, which combined with the CMARMJTAG debug firmware that has to be attached in the LPC1343, establish the debug message communications between computer and the microcontroller. After that, the CRC tool has to be copied in the appropriate folder following the given indications, and then it only remains to install an environment to work in C, in this case the Eclipse-CDT.

Eclipse-CDT is a fully functional C and C++ Integrated Development Environment and is the tool used to create the programs to control first, the eStick2 and the Xpresso Base Board, and then the head tracking system. The instructions are followed to install the Eclipse program and to how to set up a project, and to configure the preferences of this project. Once this has been done, the different programs can be written. After making the programs, a few steps have to be done to compile and prove them.

As soon as all these orders are completed, the user can started with the programs and building knowledge of how the C language, the eclipse program, the eStick2 and the microcontroller work.

The first program made is one to control the LEDs of the eStick2. Controlling the configuration of the inputs and outputs from determined pins of the microcontroller, the LEDs can be set on or off and can be changed of color, from green to red. So functions that run LEDs in various ways are created, setting on them alternating colors, with different delays of time between setting on and off one or various LEDs. Then the accelerometer,

which is integrated in the eStick2, can be used to make a new program where, depending on the position of the eStick2, different LEDs will set on.

So with these programs, the registers of the pins and their configuration are known, which is an important thing prior to establish a communication with the peripherals devices. The libraries are beginning to be used, how to call them and use them, for example the LPC13xx library and, inside it, how to work with the GPIO, exploring the possibilities it gives us.

Once the functioning of the LPC1343 is known and the elements integrated in the eStick2 controlled by the microcontroller are used, the work with the LPC1758 can be started, where the programs will be more extensive and complete. The LPC1758 is integrated in the eStick2 but it does not control the rest of integrated devices in the platform, however it is connected to the pins of the stick. The eStick2 can be combined with the Xpresso Base Board, so that the LPC1758 can manage the board and the elements that are contained in it.

In order to start using the LPC1758 putting the stick in the Xpresso Base Board and programing in Eclipse, a series of instructions have to be followed to run these programs. To be able to use and debug an application running on the LPC1758, the LPC1343 has to be configured as a remote debugger. Once the debug has been flashed on the LPC1343 and the instructions to configure the Eclipse are followed, the programs can be written and tried.

The LPCXpresso Base Board gives an extensive field testing and different communication standards can be tested. There are a lot of devices in the board, and each one uses different communication protocols, so working with these devices makes us learn how to program these protocols.

A program to manage the 7-segment display is started and the first thing done is looking at the datasheet of the board to know which pins control the display and which communication protocol is used in it. The protocol is the SPI, but in the microcontroller the SSP is intended to be used as an alternative for the SPI interface, so this is used. The pins of the LPC1758 are configured to access to the display, activate it following the datasheet and initiate the SSP controller to manage the display. Once that this is done, a program can be built to make the display do whatever is wanted: count from 1 to 9, countdown, passing alternative numbers...

Another program made to practice with the LPC1758 and the interfaces is to set up the USB of the eStick2. One of the micro-USBs of the stick is connected to the LPC1343 and the other is controlled by the LPC1758. To activate the USB interface, the instructions in the user manual of the LPC1758 have to be followed to introduce the correct commands to the registers. The bit PCUSB has to be set to power the USB interface and then the USB clock has to be configured. The corresponding pins of the LPC and their modes have to be set to control the USB interface and enable the appropriate interruptions for the objective of the program.

5 Development of the Head-Tracking System

Beginning with the program that manages the head tracking system, the first problem that had to be solved is the connection between the LPC1758 integrated in the eStick2, the PC and the camera. The connection with the PC had to be done via USB, with the mini-USB port of the eStick2 controlled by the LPC1758 and one USB port of the PC and the camera requiring connection via UART. The USB connection can be easily done with a standard mini-USB-to-USB cable, as the ones used for smartphones, but for the UART connection, a system to connect the camera to the eStick2 had to be made.

5.1 Hardware

Taking the camera out of its box, one can see that it has six pins. It is necessary to look what they are for, and connect them to the correct pins of the LPC1758 microcontroller through the pins of the eStick2. On one side of the row of pins of the camera there is a picture of a square. This pin corresponds with the 3.3 volts supply and, from this side to the other, the pins are for UART transmission, UART reception, reset, oscillator and the ground, in that order. Once the pins are identified, the corresponding pins in the eStick2 have to be localized and linked to the first. To make better connections, a support with a holed board is built, so the necessary bases to hold the camera and the eStick2 in the board are soldered on to it. Once the bases are added to the board, the correct pins of the eStick2 must be carefully identified because the pins of the camera have to be wired to these pins of the stick in the back of the board.

Looking at the manual of the microcontroller, it is noticed that, for example, the functions of transmitting and receiving for the third of the UARTs are configured in the pins P0.0 and P0.1 respectively, so these ports are searched on the pinout of the eStick2. The UART0, 2 or 3 can be used interchangeably for the communication with the camera, for this case the UART3 is the chosen option. In the pinout of the eStick2 it is seen that the pin P0.0 of the LPC1758 corresponds with the pin 13 from the row X3 of the stick and the pin P0.1 corresponds with the pin 14 from the same row. So the pins of the base of the stick and the pins of the base of the camera which agree with the mentioned pins are connected; the transmission pin of the camera with the pin 14 of the stick and the reception pin of the camera with the pin 13 of the stick. Later, when programming the software, the register of the pin 13 for UART3 transmission function and the register of pin 14 for UART3 reception mode will be set. Now, the pins for the power supply and the ground must be localized, which are in the first pins of the row X3 and X4 respectively. It is made the ground-to-ground connection with the camera and link the 3.3 volts power supplier of the stick with both the 3.3 volts pin and the reset pin of the camera, to keep it on. These connections are shown in Figure 18.

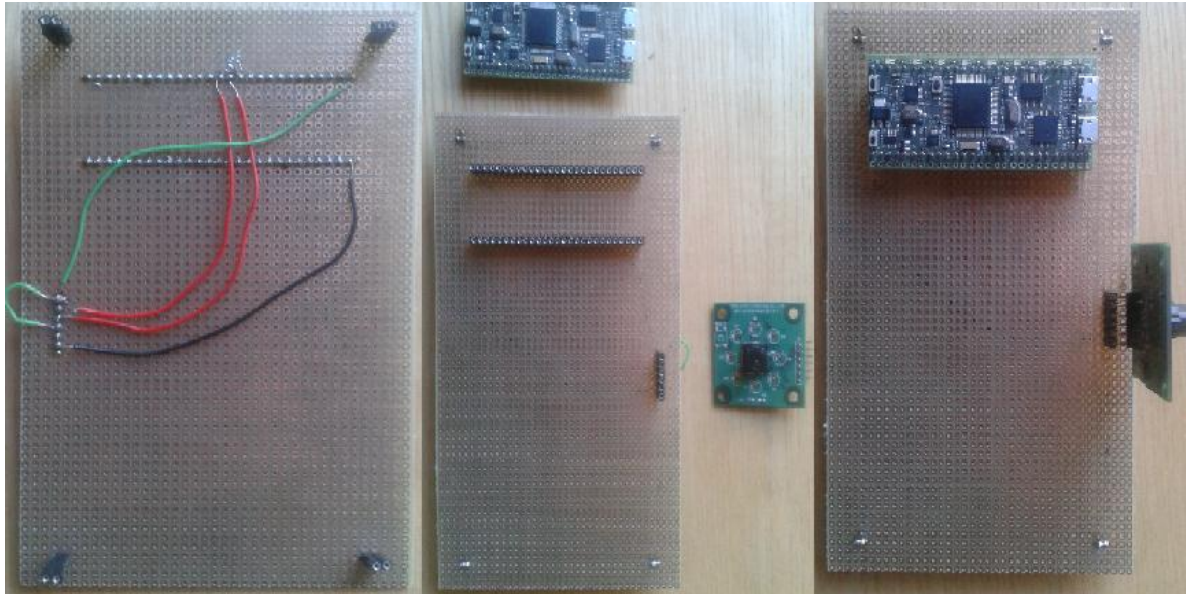


Figure 18: Hardware connections and mounting

5.2 USB Connection

The support required to establish the physical connections is assembled, so the programming of the software can be started. It begins setting up the USB communication between eStick2 and PC. On the Internet there are a lot of programs and libraries that can be used as guide or help to build the needed program. Starting with the initialization of the USB following the user manual of the microcontroller LPC1758, first it is needed to set bit PCUSB of the PCONP register, which is the bit 31 of this register, using the LPC17xx library. Then the USB pins and the corresponding modes are selected. These modes are, as it is shown in the schematic of the eStick2, the USB_CONNECT, USB_UP_LED, USB_VBUS, USB_D+ and USB_D-. The USB_CONNECT is the function 1 of the pin 2.09, 1 in the bit 18 of the PINSEL4 register with the lpc17xx_pinsel library. The USB_UP_LED is the function 1 of the pin 1.18, which is the same as set the bit 4 in the PINSEL3 register, the USB_VBUS is the function 2 of the pin 1.30, setting the bit 29 of the PINSEL3 register, the USB_D+ and the USB_D- are both in the PINSEL1 register, they are selected setting the bits 26 and 28 respectively, USB_D+ is the function 1 of the pin 0.29 and the USB_D- is the function 1 of the pin 0.30. Here is this part of the program in C:

```
PINSEL_CFG_Type PINSEL_InitStruct;

//LPC_PINCON->PINSEL4 |= 0x1<<18; //USB_CONNECT(2 WAYS TO DO)
PINSEL_InitStruct.Portnum=PINSEL_PORT_2;
PINSEL_InitStruct.Pinnum=PINSEL_PIN_9;
PINSEL_InitStruct.Funcnum=PINSEL_FUNC_1;
PINSEL_ConfigPin(&PINSEL_InitStruct);
```



```

//LPC_PINCON->PINSEL3 |= 0x1<<4; //USB_UP_LED(2 WAYS TO DO)
PINSEL_InitStruct.Portnum=PINSEL_PORT_1;
PINSEL_InitStruct.Pinnum=PINSEL_PIN_18;
PINSEL_InitStruct.Funcnum=PINSEL_FUNC_1;
PINSEL_ConfigPin(&PINSEL_InitStruct);

//LPC_PINCON->PINSEL3 |= 0x10<<28; //USB_VBUS(2 WAYS TO DO)
PINSEL_InitStruct.Portnum=PINSEL_PORT_1;
PINSEL_InitStruct.Pinnum=PINSEL_PIN_30;
PINSEL_InitStruct.Funcnum=PINSEL_FUNC_2;
PINSEL_ConfigPin(&PINSEL_InitStruct);

//LPC_PINCON->PINSEL1 |= 0x1<<26; //USB_D+ (2 WAYS TO DO)
PINSEL_InitStruct.Portnum=PINSEL_PORT_0;
PINSEL_InitStruct.Pinnum=PINSEL_PIN_29;
PINSEL_InitStruct.Funcnum=PINSEL_FUNC_1;
PINSEL_ConfigPin(&PINSEL_InitStruct);

//LPC_PINCON->PINSEL1 |= 0x1<<28; //USB_D- (2 WAYS TO DO)
PINSEL_InitStruct.Portnum=PINSEL_PORT_0;
PINSEL_InitStruct.Pinnum=PINSEL_PIN_30;
PINSEL_InitStruct.Funcnum=PINSEL_FUNC_1;
PINSEL_ConfigPin(&PINSEL_InitStruct);

// enable PUSB
LPC_SC->PCONP |= 0x1<<31;

```

Note that the pins can be selected in two different ways. It is declared PINSEL_InitStruct as a PINSEL_CFG_type structure to select the port, pin and function, and then PINSEL_ConfigPin is used to set the chosen pin function in the microcontroller. With the other way, the bit of the wanted function in the LPC1758 with the PINSEL register is directly set.

Now it is needed to enable the device controller clocks. This is done setting DEV_CLK_EN and AHB_CLK_EN bits in the USBClkCtrl register, with this name in the LPC17xx library. The DEV_CLK_EN bit corresponds to the bit 1 in the register and the AHB_CLK_EN bit to the 4 bit in the register, so they are set. Once that is done, the same bits in the USBClkSt register has to be checked because it holds the clock availability status and, if the clocks are set, the software can go ahead with the register access. The code to enable the clocks:

```

LPC_USB->USBClkCtrl = 0x1A;          /* Dev clock, AHB clock enable */
while ((LPC_USB->USBClkSt & 0x1A) != 0x1A);

```

Instead of 0x1A, 0x12 could have been put to set the wanted bits, but in examples in Internet it is done with 0x1A, so that way is followed; the rest of the bits apart from the two talked about are reserved and not defined. With the “while”, wait until the bits are set.

At this time, a kind of initialization of the registers that control the interruptions it is made, clearing them all and without setting any interruption or giving them any priority. This registers control the device interruptions and the endpoint interruptions, so in both have to make this initialization:

```
LPC_USB->USBDevIntEn = 0;
LPC_USB->USBDevIntClr = 0xFFFFFFFF;
LPC_USB->USBDevIntPri = 0;

LPC_USB->USBEpIntEn = 0;
LPC_USB->USBEpIntClr = 0xFFFFFFFF;
LPC_USB->USBEpIntPri = 0;
```

Writing a one to a bit in the Interrupt Enable register (USBxxIntEn, xx can be for Dev, device, or for Ep, endpoint) enables the corresponding bit in USBxxIntSt to generate an interrupt on one of the interruption lines when set. Writing a one to a bit in the Interrupt Clear register (USBxxIntClr) clears the corresponding bit in USBxxIntSt, so if an interruption of the type of the clear bit occurs, it has no effect in the program. The USBxxIntSt is a register where are located the allowed interruptions that are controlled by the USBxxIntEn and USBxxIntClr. With the USBxxIntPri, the priority of the interruption can be controlled, high priority with a 1 and low priority with a 0 in the bit corresponding to the interruption. The endpoint interruptions are 32, equivalent to 16 endpoints with transmission and reception, from the bit 0 with Endpoint0 RX to the bit 31 with the Endpoint15 TX in the registers which control this kind of interruptions. The device interruptions are 10: ERR_INT, EP_RLZED, TxENDPKT, RxENDPKT, CDFULL, CCEMPTY, DEV_STAT, EP_SLOW, EP_FAST, and FRAME, from the bits 9 to 0 respectively in the registers that control these interruptions. These will be later explained.

Continuing with the initialization, only ACK and not NAK from the endpoints can provoke an interrupt. This function does that:

```
USBHwNakIntEnable(0);
```

Inside this function:

```
void USBHwNakIntEnable(U8 bIntBits)
{
    USBHwCmdWrite(CMD_DEV_SET_MODE, bIntBits);
}
```

What it does is write the value bIntBits (0 in this case) in the command Set Mode (CMD_DEV_SET_MODE == 0xF3) of the SIE. The SIE is the Serial Interface Engine and it handles the transfer of data between the endpoint buffers in EP_RAM and the USB bus, so it controls what is read from and is written in the endpoints buffers. The functions of this

block include: synchronization pattern recognition, parallel/serial conversion, bit stuffing/de-stuffing, CRC checking/generation, PID verification/generation, address recognition, and handshake evaluation/generation. These commands, as the Set Mode, are used to access to the registers and functions of the SIE, and consist on a command code followed by optional data bytes. Two registers are used for this access, USBCmdCode and USBCmdData. The USBCmdCode register is divided in CMD_PHASE, from bit 8 to 15, and CMD_CODE or CMD_WDATA, from bit 16 to 23. In the CMD_PHASE there are 3 possibilities:

- 'Write' with the value 0x01
- 'Read' with the value 0x02
- 'Command' with the value 0x05

If in the CMD_PHASE field there is 'Read' or 'Command', then the field name is CMD_CODE and it contains the code for the command, and if there is 'Write', the field is CMD_WDATA and it contains the command write data. The SIE commands are collected in Table 3:

Command name	Recipient	Code(Hex)	Data Phase
Set Address	Device	D0	Write 1 byte
Configure Device	Device	D8	Write 1 byte
Set Mode	Device	F3	Write 1 byte
Read Current Frame Number	Device	F5	Read 1 or 2 bytes
Read Test Register	Device	FD	Write 1 byte
Set Device Status	Device	FE	Write 1 byte
Get Device Status	Device	FE	Read 1 byte
Get Error Code	Device	FF	Read 1 byte
Read Error Status	Device	FB	Read 1 byte
Select Endpoint	Endpoint xx	xx (same as the endpoint)	Read 1 byte (optional)
Select Endpoint/ Clear Interrupt	Endpoint xx	40 + xx	Read 1 byte
Set Endpoint Status	Endpoint xx	40 + xx	Write 1 byte
Clear Buffer	Selected Endpoint	F2	Read 1 byte (optional)
Validate Buffer	Selected Endpoint	FA	None

Table 3: SIE commands

They will be explained when it is needed. The USBCmdData contains the read data from a command when there is 'Read' on the CMD_PHASE. When a command is write in the USBCmdCode, the CCEMPTY bit of the USBDevIntSt register (bit 4) changes to a 0, because the reset value is 1 and means that the USBCmdCode is empty, and when the USBCmdData register has data to read, it is full, the CDFULL bit of the USBDevIntSt register (bit 5) is set.

The operation mode for these commands is, first, clear CDFULL and CCEMPTY bits with USBDevIntClr register. Then, in the USBCmdCode register, put the wanted command code in the CMD_CODE and the sequence 0x05 (Command) in the CMD_PHASE field, and wait until USBCmdCode is empty again, with a 1 in the corresponding CCEMPTY bit of USBDevIntSt. This part always must be done and, when this is accomplished, clear CCEMPTY again. If the purpose is read, the same command code has to be put, as well as the sequence 0x02 (Read) in the CMD_PHASE field. Then wait until the bit 5 of USBDevIntSt (CDFULL) is set, that means there is data to read in the USBCmdData register, clear the CDFULL and save the data from USBCmdData wherever is wanted. If the purpose is to write, put in the CMD_WDATA field the wanted data to write and in the CMD_PHASE the sequence 0x01 (Write). Then wait until CCEMPTY is set in USBDevIntSt and clear it. There are some functions in the libraries to do what is described here:

```
static void USBHwCmd(U8 bCmd)
{
    // clear CDFULL/CCEMPTY
    LPC_USB->USBDevIntClr = CDFULL | CCEMPTY;
    // write command code
    LPC_USB->USBCmdCode = 0x00000500 | (bCmd << 16);
    Wait4DevInt(CCEMPTY);
}
```

This function manages the first part described, the common for write and read, with the wanted command selection. The following is the function for the read mode:

```
static U8 USBHwCmdRead(U8 bCmd)
{
    // write command code
    USBHwCmd(bCmd);
    // get data
    LPC_USB->USBCmdCode = 0x00000200 | (bCmd << 16);
    Wait4DevInt(CDFULL);
    return LPC_USB->USBCmdData;
}
```

And this is the function for the write mode:

```
static void USBHwCmdWrite(U8 bCmd, U16 bData)
{
    // write command code
```

```

        USBHwCmd(bCmd);
        // write command data
        LPC_USB->USBCmdCode = 0x00000100 | (bData << 16);
        Wait4DevInt(CCEMTY);
    }

```

In these three functions, the field “bCmd” is for the wanted command code in byte and the “bData” field is for the byte data to write in the selected command. The last is the one used in the function `USBHwNakIntEnable(0)` to use the Set Mode command as it has been shown before.

After this preparation process of the USB pins and interruptions, encompassed in the `USBHwInit()` function of the `usbhw_lpc` library, it is the turn of the interrupt handlers. With the function `USBHwRegisterDevIntHandler(HandleUsbReset)` of the `usbhw_lpc` library, the `DEV_STAT` interruption can be enabled, which corresponds with the bit 3 in the `USBDevIntXx` registers. This interruption occurs when USB bus is reset, USB suspends change or when connect change event happens. Now, following some internet examples, the same of enabling the device interruption is done, but with the endpoints interruptions:

```

USBHwRegisterEPIntHandler(0x00, USBHandleControlTransfer);
USBHwRegisterEPIntHandler(0x80, USBHandleControlTransfer);

```

With these functions, the endpoints interruptions for the EP0 and the EP8 are enabled, as well as the `EP_SLOW` interruption, which is the slow endpoint interruption for endpoints with no priority, and established `USBHandleControlTransfer` as a handler on endpoint transfers. Once this is done, the endpoints have to be enabled and configured. Configure an endpoint means to realize it, to reserve a buffer space for the endpoint and to establish a maximum packet size for the endpoint. When this is done, wait for setting the `EP_RLZED` bit in the `USBDevIntSt` register, which means that the endpoint is correctly done, and then clear it. This is done with the function `USBHwEPRealize(idx(endpoint nº), wMaxPacketSize)` and then the endpoint is enabled with the function `USBHwEPEnable(idx, TRUE)`, which uses the Set Endpoint Status command to write in the wanted endpoint to enable it. Both functions are gathered in the function `USBHwEPConfig`, and to set the wanted endpoints the order to put in the program is:

```

USBHwEPConfig(0x00, MAX_PACKET_SIZE0);
USBHwEPConfig(0x80, MAX_PACKET_SIZE0);

```

Following the examples, to finish this initialization of the USB, a function of the usb control library is needed to be used, to register a callback for the handlers of the interruptions. This function is:

```

USBRegisterRequestHandler(REQTYPE_TYPE_STANDARD, USBHandleStandardRequest,
abStdReqData)

```

Now the initialize of the USB is finished, but more things have to be done to establish the connection. First, a pointer to a descriptor block has to be registered. This block contains all descriptors for the device. In internet there are a lot of examples of descriptor of USB devices, and, in this case, it is needed a USB connection, so the device descriptor used is:

```
static const U8 abDescriptors[] = {

/* Device descriptor */
0x12,
DESC_DEVICE,
LE_WORD(0x0110),          // bcdUSB
0x00,                     // bDeviceClass
0x00,                     // bDeviceSubClass
0x00,                     // bDeviceProtocol
MAX_PACKET_SIZE0,        // bMaxPacketSize
LE_WORD(0xFFFF),         // idVendor
LE_WORD(0x0001),         // idProduct
LE_WORD(0x0100),         // bcdDevice
0x01,                     // iManufacturer
0x02,                     // iProduct
0x03,                     // iSerialNumber
0x01,                     // bNumConfigurations

// configuration
0x09,
DESC_CONFIGURATION,
LE_WORD(0x22),            // wTotalLength
0x01,                     // bNumInterfaces
0x01,                     // bConfigurationValue
0x00,                     // iConfiguration
0x80,                     // bmAttributes
0x32,                     // bMaxPower

// interface
0x09,
DESC_INTERFACE,
0x00,                     // bInterfaceNumber
0x00,                     // bAlternateSetting
0x01,                     // bNumEndpoints
0x03,                     // bInterfaceClass = HID
0x00,                     // bInterfaceSubClass
0x00,                     // bInterfaceProtocol
0x00,                     // iInterface

// HID descriptor
0x09,
DESC_HID_HID,             // bDescriptorType = HID
LE_WORD(0x0110),         // bcdHID
0x00,                     // bCountryCode
0x01,                     // bNumDescriptors = report
DESC_HID_REPORT,         // bDescriptorType
LE_WORD(sizeof(abReportDesc)),

// EP descriptor
0x07,
DESC_ENDPOINT,
INTR_IN_EP,              // bEndpointAddress
0x03,                     // bmAttributes = INT
LE_WORD(MAX_PACKET_SIZE), // wMaxPacketSize
}
```

```

10,                                     // bInterval

// string descriptors
0x04,
DESC_STRING,
LE_WORD(0x0409),

// manufacturer string
0x0E,
DESC_STRING,
'L', 0, 'P', 0, 'C', 0, 'U', 0, 'S', 0, 'B', 0,

// product string
0x12,
DESC_STRING,
'P', 0, 'r', 0, 'o', 0, 'd', 0, 'u', 0, 'c', 0, 't', 0, 'X', 0,

// serial number string
0x12,
DESC_STRING,
'D', 0, 'E', 0, 'A', 0, 'D', 0, 'C', 0, 'O', 0, 'D', 0, 'E', 0,

// terminator
0
};

```

If the USB device is wanted as interface for a mouse or a joystick, the “interface” field of the descriptor block has to be changed. So the function that registers the pointer to the block is:

```
USBRegisterDescriptors(abDescriptors)
```

Following some internet examples, now some handlers for requests have to be registered. Let's see this registers:

```

// register HID standard request handler
USBRegisterCustomReqHandler(HIDHandleStdReq);

// register class request handler
USBRegisterRequestHandler(REQTYPE_TYPE_CLASS, HandleClassRequest,
abClassReqData);

// register endpoint
USBHwRegisterEPIntHandler(INTR_IN_EP, NULL);

// register frame handler
USBHwRegisterFrameHandler(HandleFrame);

```

In the first register, HIDHandleStdReq tries to service any HID specific request and the USBRegisterCustomReqHandler function guides the program to it as a callback function. The second function registers a callback for HID class request handler with HandlerClassRequest as handler and REQTYPE_TYPE_CLASS to define the class type. With the function USBHwRegisterEPIntHandler and with INTR_IN_EP, the endpoint 8 and 1 are enabled, but give a NULL callback function. The USBHwRegisterFrameHandler function

enables the FRAME interrupt which corresponds with the bit 0 of the USBDevIntXx registers, and this interruption occurs every 1ms. It is used for isochronous packet transfers and the function gives the HandleFrame as callback function too.

Once the handlers are prepared, the USB has to be connected. This is done with the function USBHwConnect(TRUE), so that with TRUE, a 0 is written in the connect bit (bit 0) of the Set Device Status command. It means that the CONNECT pin go high, so the connection with the USB Bus is done. When the connection is established and all is prepared, a loop is built to call the USB interrupt handler continuously:

```
while (1) {  
    USBHwISR();  
}
```

The USBHwISR() function, which is the USB interrupt handler, is included in the usbhw_lpc library.

With all of this, the program of the USB connection is finished. The describe functions developed are in the different libraries, such as usbstdreq, usbinit, usbhw_lpc or usbcontrol, and the handlers are described in the actual USB connect program.

5.2.1 USB Program: Joystick

To check that the USB connection works properly, a program is built that will help later in the aim of moving the pointer of the mouse with the PAC7001 camera respect to the set of LEDs. A mouse joystick is going to be configured with the joystick of the LPCXpresso Base Board, managed by the LPC1758 and connected to the computer via USB. The previous USB program is used, but it must be adapted to act as a mouse attending to the movement of the Board joystick.

One of the changes is in the descriptor of the USB device is in the interface field of the descriptor, the byte of interface number has to be changed to 0x01, because now the mouse function is needed, and the byte of interface protocol must be 0x02 because it corresponds to Mouse protocol. After changing that, the initialization of the USB stack is the same, as well as the function to register the pointer to the device descriptor, the function to register the HID standard request handler, the one for the class request handler and the function that registers the endpoints. A report descriptor of the data is added when the USB is used as an interface for a mouse, and it is used in the handler of standard request. This report is generated by a HID descriptor tool program, which can generate descriptors for other purposes or protocols. Another function that has to be changed is the handler of the frame interruptions, to provide a real mouse reports. This handler is the responsible of the movement of the cursor in the computer. It is needed to introduce a different data to the endpoint buffer (computer) from the one it previously had. This data is the displacement of the mouse, along the X axis, the Y axis and the press button of the

mouse. These are defined as a structure called `HIDDMouseInputReport` and the variables are `bmButtons`, `bX` and `bY`. The final structure of the definition is:

```
typedef struct {
    unsigned char bmButtons;    /// Bitmap state of three mouse
    buttons.                    /// Pointer displacement along the X
    signed char bX;              axis.
    signed char bY;              /// Pointer displacement along the Y
    axis.
} __attribute__((packed)) HIDDMouseInputReport;
```

Once the structure is defined, it is necessary to initialize it, and it is done with the function `HIDDMouseInputReport_Initialize(HIDDMouseInputReport *report)`, where “*report” is the name given to the structure, in this case “MouseInputReport”. This function equals to 0 the three variables of the structure, so they are initialized.

The variables that control the cursor movement are prepared, but remain the joystick controls. Looking at the pinout of the eStick2, it is seen that the joystick is controlled by the pins 2.0, 2.1, 2.2, 2.3 and 2.4 in the corresponding function GPIO Port. Here in Table 4 is the list of the controls:

Command	Function
Press Joystick	GPIO Port 2.0
Joystick Right	GPIO Port 2.1
Joystick Up	GPIO Port 2.2
Joystick Left	GPIO Port 2.3
Joystick Down	GPIO Port 2.4

Table 4: Functions for the joystick program

Now that it is known which pins control the joystick, a function to check is made, in the FIOPIN register of the port 2, the bits corresponding with these pins. The current state of digital pins can be read from the FIOPIN register so, if the joystick is moved to the right, the bit 1 of the FIOPIN register of the port 2 is set and, if it is moved to the left, the bit 3 of this register is set. The bits from 0 to 4 in the FIOPIN register are checked and then put them in order in one byte, invert this byte and pass it with an AND operator through a mask of 0xff. Finally it is obtained the command sent by the joystick in a one byte variable. The order of the bits from this variable, from the bit 0 to the bit 4, are joystick right, joystick left, joystick down, joystick up and select joystick, so depending on which of these bits are set, the movement of the joystick is known and so the movement that the pointer has to do. The described function is:

```

void JoystickRead(int *pi_JoystickState)
{
    int i_up, i_dn, i_l, i_r, i_sel;
    int i_State;

    i_sel = (LPC_GPIO2->FIOPIN>>0) & 1;
    i_r = (LPC_GPIO2->FIOPIN>>1) & 1;
    i_up = (LPC_GPIO2->FIOPIN>>2) & 1;
    i_l = (LPC_GPIO2->FIOPIN>>3) & 1;
    i_dn = (LPC_GPIO2->FIOPIN>>4) & 1;

    i_State = (i_sel<< 4) | (i_up<<3) | (i_dn<<2) | (i_l<<1) |(i_r);
    i_State = (~i_State) & 0xff;
    *pi_JoystickState = i_State;
}

```

In the variable appears “*pi_JoystickState”. In this case the name of the variable is “i-JoystickState”, the state of the joystick, where it is moved to. To know which of this is, it is compared with a series of defined parameters. Each of these parameters correspond with a state of the joystick, so that the JOYSTICK_CLICK parameter has the value 0x10, the JOYSTICK_UP parameter has 0x08 and so on, so it is easy to see which of these parameters has the same value, the same bit set as the variable “i-JoystickState”. Once the state of the joystick is identified, the correct movement in the X axis or in the Y axis to the cursor is needed to be sent. As it was said before, this movement is controlled by the variables of the HIDDMouseInputReport structure, a value to these variables is given depending on the state of the joystick. The X axis is the horizontal axis, and the Y is the vertical axis and the movement of the cursor for each movement of the joystick is 10 units, positives when moved right and down and negatives when moved left and up. The comparison with the parameters and the corresponding send of movement orders are in a loop together with the USB interrupt handler, to call them continuously.

One of these blocks of comparison and send movement orders, for the UP state of the joystick is:

```

if(i_JoystickState & JOYSTICK_UP)
{
    MouseInputReport.bY = -10;
    MouseInputReport.bX = 0;
    MouseInputReport.bmButtons = 0;
}

```

So finally the program is done. It is needed to integrate the eStick2 in the XPresso Base Board, make relevant connections and at the end, the pointer of the mouse can be moved with the joystick of the Board. It is concluded that the USB connection works and the instructions for the mouse too, and they will be needed for the main program of the head tracking system.

5.2.2 USB Program: Send/Receive characters

Now another program for the USB communication is done, to receive characters via USB from the keyboard of the computer and to send these characters back to the computer and show them in the screen, something that will be helpful later. The same scheme as the used to do the joystick program is followed, with the same initialization of the USB stack. Then comes the `USBRegisterDescriptor` function, to set a pointer to the descriptor block of the USB device. In this case, the descriptor of the USB device is different from the descriptor of the joystick program, because the USB is not an interface for a mouse protocol, is only a bridge to exchange data. So instead of define the mouse protocol, is needed to define which endpoints are used to send the data and which to receive it. There are a lot of examples in the Internet of these types of descriptors and, in this case, it is used the endpoint 0 TX for the transmission of data via USB (`BULK_OUT_EP`) and endpoints 1Rx and 0 Rx for the reception of data (`BULK_IN_EP`). Once there is an instruction to register a pointer to the descriptor, continue with the function that calls the function to handle the USB class request. `USBRegisterRequestHandler` is the function that calls the handler of the USB class request, and this handler is `HandleClassRequest`.

After that, is needed to continue with the endpoints handlers, which are registered with the function `USBHwRegisterEPIntHandler`. Three different handlers have to be registered for different endpoints; the endpoint for the notifications as in the joystick program (`INT_EN_EP = 0x81`) with null handler, the endpoint for the outgoing data (`BULK_OUT_EP`), selecting `BulkOut` as handler, which controls the FIFO, get the data from it, write this data into an intermediate buffer to send it later to an endpoint and control the NAK interruptions. For the endpoint of the incoming data (`BULK_IN_DATA`) `BulkIn` is selected as handler, which controls the getting data from an intermediate buffer. This buffer has data from the endpoint which transmits, and the handler put the data into a FIFO. The form to register a handler for an endpoint is:

```
USBHwRegisterEPIntHandler(U8 bEP, TFnEPIntHandler *pfnHandler)
```

Where “bEP” is the field for the number of the endpoint and “*pfnHandler” is the pointer to the handler. The endpoints handler functions are:

```
USBHwRegisterEPIntHandler(INT_IN_EP, NULL);  
USBHwRegisterEPIntHandler(BULK_OUT_EP, BulkOut);  
USBHwRegisterEPIntHandler(BULK_IN_EP, BulkIn);
```

Now is turn of the frame handler. Select `USBFrameHandler` with the `USBHwRegisterFrameHandler`, which points at this handler as frame handler. After that, the interruptions have to be activated when both, successful and NAK transactions occurs in an input endpoint. This is done setting the bit 5 in the Set Mode command and this is done with the function:

USBHwNakIntEnable(U8 bIntBits)

Where “bIntBits” is the byte wanted to be written or the bits wanted to be set in the SET MODE command. With USBHwNakIntEnable(INACK_BI), where INACK_BI is (1 << 5 = 0x20), the bit 5 is set and these desired interruptions are activated. Once the interruptions are enabled, it is needed to initialize the VCOM port, which is initialize the transmission FIFO and the reception FIFO, initialize his pointers. This is done with the function VCOM_init() and all the FIFO instructions are located in the library “serial_fifo”. When it is switched on, the USB bus is connected with the function USBHwConnect(TRUE). After that, a loop is started with the getting of characters from the computer keyboard and then the put back of the character on the USB bus, which can be the same character or this one treated.

For the getting of characters there is the function VCOM_getchar(), which takes the characters in order from the Rx FIFO queue. This FIFO is filled by the BulkIn handler with the characters pulsed in the keyboard. The VCOM_getchar function returns to the main program the first character of the FIFO queue and advanced the FIFO pointer to the next character, all of these aided by the program “fifo_get” from the library serial_fifo. After calling this VCOM_getchar function and store the obtained character in a variable, this treated character is needed to be put back to the computer to show it. This is done with the function VCOM_putchar, where the character to show is an input variable. Inside the function, with the fifo_put order, the character is put in the Tx FIFO queue to send it to the endpoint and advance in the Tx FIFO pointer to continuing filling the queue. In this case, the treatment that is applied to the received character is adding 1 to his value, so if the ‘a’ button of the keyboard is pushed, the program will send back a ‘b’. Put the VCOM_putchar function in an IF loop where the program gets in if the variable is not EOF:

```
while (1) {
    c = VCOM_getchar();
    if (c != EOF) {
        VCOM_putchar(c + INCREMENT_ECHO_BY );
    }
}
```

To see the characters back in the computer a hyper terminal is used. In some Windows systems the hyper terminal is not included, so a free version can be downloaded, as Hyper Terminal Private Edition. For the proper functioning of the hyper terminal and the detection of the USB cable from the USB device of the LPC1758 in the eStick2 to the computer, when it is required, Windows has to be directed to a special file which is found in examples in internet, “usbser.inf”. With this file, Windows creates an extra COMX port for the mentioned connection that can be opened in the hyper terminal. To see the treated characters that are sent back from the program, as well as the typed characters, is necessary to configure the hyper terminal. The hyper terminal should be set to append line

feeds to incoming line ends and to echo typed characters locally, so the typed characters can be compared with the treated ones and check that the program works.

5.3 UART Connection

Once the USB connection is done, is turn of the UART connection. As it was done with the USB, the manual of the LPC1758 is followed to establish the connection. It is needed to remember that the physical links are done with the UART3 pins, so it is necessary to configure the UART3 registers to set up well the connection.

First the bit PCUART3 in the register PCONP has to be set up to turn on power to UART3. This bit is the number 25 of the register, and it is saved in the parameter PCUART3_POWERON, so power on is done with the instruction:

```
LPC_SC->PCONP |= PCUART3_POWERON
```

Then the peripheral clock for the UART3 is needed to be selected, which is in the PCLKSEL1 register. The corresponding bits for the PCLK_UART3 are the bits 18 and 19 of this register and depend on the values of these bits, the clock is set in one way or another with respect to the core clock(CCLK). So that, a 00 means the PCLK is equal to CCLK/4, a 01 means PCLK= CCLK, a 10 PCLK= CCLK/2 and 11 PCLK= CCLK/8. In this case the clock is set to a 1/4 of the core clock, so first “clean” the PCLK_UART3 bits of the PCLKSEL1 register and let them with a 00 value:

```
LPC_SC->PCLKSEL1 &= ~(PCLK_UART3_MASK);  
LPC_SC->PCLKSEL1 |= (0 << PCLK_UART3);
```

Now the UART3 pins have to be selected in the correct function, setting them in the PINSEL register. The pin who controls the UART3 transmission is the P0.0 and the one for the UART3 reception is the P0.1, so both are in the lower half of the Port 0 that means this functions are controlled by the PINSEL0 register. In both cases, the wanted function to operate the pins as UART3 transmission and reception respectively is the function 2. So the value 10 (2 in hexadecimal) is put in the characteristic bits of each pins, bits 0 and 1 for pin P0.0 and 2 and 3 for pin P0.1, in the PINSEL0 register. These bits can be cleared first to ensure the values are correctly written in the register:

```
LPC_PINCON->PINSEL0 &= ~0x0f;  
LPC_PINCON->PINSEL0 |= 0x2<<0; //TxD3  
LPC_PINCON->PINSEL0 |= 0x2<<2; //RxD3
```

The lines of communication are setting, now the format of the data character that passes through them has to be defined. This is done in the register U3LCR and it is controlled with the LCR command over LPC_UART3. In this register, the length of the

send/receive word can be decided, enabled or not the parity and selected the type of it or enabled or not the access to Divisor Latches with the Divisor Latch Access Bit (DLAB). The Divisor Latch is divided in DLL, which is his least significant byte, and the DLM, which is his most significant byte, and the full value is used to divide the PCLK in order to generate the baud rate clock. The DLAB must be 1 to access to these DLL and DLM register and select a value for them, and must be 0 to enable interruptions and realize other functions. The bit description of the LCR is in Table 5:

Bit	Symbol	Value	Description
1:0	Word Length Select	00	5 bit character length
		01	6 bit character length
		10	7 bit character length
		11	8 bit character length
2	Stop Bit Select	0	1 stop bit
		1	2 stop bit
3	Parity Enable	0	Disable parity gen.
		1	Enable parity gen.
5:4	Parity Select	00	Odd parity
		01	Even parity
		10	Forced "1" stick parity
		11	Forced "0" stick parity
6	Break Control	0	Disable break transm.
		1	Enable break transm.
7	DLAB	0	Disable access to DL
		1	Enable access to DL
8:31	-	-	Reserved

Table 5: Description of the LCR

In this case, the data character is programed of 8 bits, 1 stop bit, no parity and setting the DLAB, so the value to introduce in the U3LCR register is 0x83 and the command used to do it is:

```
LPC_UART3->LCR = 0x83;    // 8 bits, no Parity, 1 Stop bit, DLAB=1
```

Now the DLL and DLM values have to be selected to have the wanted baud rate. The general formula to estimate the baud rate of the UART3 is ([30], p. 313):

$$UART3baudrate = \frac{PCLK}{16 \times (256 \times (U3DLM + U3DLL)) \times (1 + \frac{DivAddVal}{MulVal})} \quad [1]$$

Where PCLK is the peripheral clock, U3DLM and U3DLL are the baud rate divider registers and DivAddVal and MulVal are the fractional baud rate generator specific parameters. In this case, the division between these two parameters is 0 because they have not an assigned value, the reset value for DivAddVal is 0 and for MulVal is 1, and so have no impact in the baud rate. The PCLK of the UART3 is defined as $\frac{1}{4}$ of the core clock, and the baud rate is a chosen value, the value of DLM and DLL can be obtained, where the DLM is the result of the final division and the DLL is the modulo, the integer remainder of this division, which is:

$$PCLK / (16 \times 256 \times UART3baudrate) \quad [2]$$

The commands used in the program to find the values for the U3DLM and U3DLL registers and to give these values to these registers are:

```
// PCLK_UART3 is being set to 1/4 of SystemCoreClock
pclk = SystemCoreClock / 4;
Fdiv = ( pclk / 16 ) / baudrate ;      // Set baud rate
LPC_UART3->DLM = Fdiv / 256;
LPC_UART3->DLL = Fdiv % 256;
```

Where “baudrate” is the wanted baud rate for the UART3 communication and is an input variable for the whole program of UART3 initialization. Once the baud rate of the UART3 is selected, it is needed to enable the UART3 Rx and Tx FIFOs for proper UART operation in transmission and reception. This is done in the U3FCR register, where setting the bit 0 enable both Rx and Tx FIFOs, setting the bit 1 reset the Rx FIFO and setting the bit 2 reset the Tx FIFO. So the hexadecimal value 7 is assigned to the register U3FCR to enable all, and also in the U3LCR register the DLAB is disabled to allow enable interruptions, but maintaining the rest of the setting bits in the previous access to this register:

```
LPC_UART3->LCR = 0x03;    // 8 bits, no Parity, 1 Stop bit DLAB = 0
LPC_UART3->FCR = 0x07;    // Enable and reset TX and RX FIFO
```

With this, the program to initialize the UART3 is finished. The described functions are collected in one to do the initialization, and is in this one where “baudrate” is an input variable:

```
void UART3_Init(int baudrate)
```

As with this function, a communication via UART can be started with a device, now it is necessary to build functions to send and receive characters over UART3. The register that provides information about the existence or not of data to receive, or the possibility of sending a character in the UART3, is the U3LSR register. The main bits of this register, to carry out these purposes, are the Receiver Data Ready (RDR) and the Transmitter Holding

Register Empty (THRE). The RDR bit is the bit 0 of the U3LSR register and is set when the UART3 receiver FIFO is not empty, when the U3RBR holds an unread character, and it is cleared when the UART3 receiver FIFO is empty. The U3RBR register is the top byte of the UART3 Rx FIFO, it contains the oldest received byte and can be read via the bus interface, but to do it the DLAB must be 0. The THRE bit is the bit 5 of the U3LSR register and is set when the U3THR register is empty and clear when U3THR contains valid data, the reset value is 1. The U3THR is the top byte of the UART3 Tx FIFO, is the newest character in the Tx FIFO and can be written via bus when the DLAB is 0. Writing in the U3THR register causes the data to be stored in the UART3 Tx FIFO.

Looking what is just described, to do the program to send characters over UART3, the THRE bit and the U3THR register are used, and for the program to receive data is used the RDR bit and the U3RBR register. For the receive data program, first the RDR bit of the U3LSR register has to be checked, until it is set, what means the receiver FIFO is not empty and there is something to read. When this is the case, the receiver character has to be read from the U3RBR and stored in a variable, to use it as output of this program to receive. The name of this function is UART3_Getchar:

```
char UART3_Getchar()
{
    int c;
    while( (LPC_UART3->LSR & LSR_RDR) == 0 );
    c = LPC_UART3->RBR;
    return c;
}
```

For the transmission program, the bit THRE has to be checked until it is set, what means the U3THR register is empty, so the Tx FIFO is empty to receive data to send. When this bit is set, the character wanted to send over the UART3 can be written in the U3THR. This character is an input variable of this sending program, in this case named "c". The name of the program is UART3_Sendchar:

```
void UART3_Sendchar(int c)
{
    while( (LPC_UART3->LSR & LSR_THRE) == 0 );

    LPC_UART3->THR = c;
}
```

With the function for the initialization of the UART3 and these two functions, to send and receive characters via UART3, a program can be built to communicate with the PAC7001 camera. These last functions are needed to first configure the camera, sending the parameters for the camera registers, and second, to receive the information from what the camera can see.

5.4 Camera configuration and communication

Now start with the camera, the configuration and the communication between it and the LPC1758. For knowing how to work with the PAC7001, the datasheet of it is followed. To configure the camera in the wanted way, a series of commands are sent in a specific order, but first of all, the mode of the camera has to be changed. When the camera is power on, it starts in an “Initial mode” as a default mode. The first thing that has to be done is send the command “Check device”, which is done sending the hexadecimal value 0xEA. With this command, the chip of the camera starts, is a kind of password for it. Then, all the wanted registers can be set up, or read, but for this, a combination of instructions has to be followed. After the work with the registers is done, the camera has to be switched to the “Operation mode”, sending the data 0x8D to the camera. Once the PAC7001 has entered this mode, it starts to output the objects features; it “sends” determined characteristics of the object that capture to the microcontroller. In this case, “send” means that the microcontroller takes this information from the camera, with the previously described function UART3_getchar. To get out of this “Operation mode” and the output of data from the camera, 0x8E is sent to the PAC7001 and it will go back to the “Initial mode”. The sending of data from the microcontroller to the camera is done with the function UART3_sendchar, to work with the registers. Now, in Table 6 the described process to access to the modes of the camera is presented, and the instructions that have to be followed to set or read the registers of the PAC7001:

Command Order	Command Content	Sensor ACK
Check Device	0xEA	“Tracking V01”
Set Register	0x10 + Register Number + Register Value	0x10
Read Register	0x11 + Register Number	Register Value (High Byte First)
Switch to “Operation Mode”	0x8D	0x8D

Table 6: Set camera modes

As it is shown, to set a register, first 0x10 has to be sent to the camera, following by another message with the number of the register wanted to be set, and then another message with the value wanted to be introduced in the selected register. Notice that the camera generates an ACK with every command it receives. Looking at the system to setting a register, a function is made to do it directly, CameraSet (char RegNum, char RegValH, char RegValL), where RegNum is the number of the register to set, RegValH is the high byte value for those registers that have two value bytes and RegValL is the low value for these registers or the unique value for those register with only one byte value. In the function, the first step is send a 0x10 to the camera, to indicate that a register is going

to be set, and then continuing with the sending of the RegNum, RegValH and RegValL values with the UART3_sendchar function to select the registers and the proper values. But the camera needs a time to process the information and the messages cannot be sent one after the other without waiting a little, so the function Delay (int secs) is used. The field secs is for a number which is multiplied by 1000, and then the function entered in a loop that finish when reach this obtained number, from 0 adding 1 each iteration:

```
void Delay (int secs)
{
    int i = 0;
    while ( i <= (secs*1000))
    {
        i++;
    }
}
```

So with this function, a time is given to the camera to process the information, putting it just after every UART3_sendchar function. Once all the commands required to set a register are sent, to finish with the CameraSet function, the Rx FIFO queue is read with the UART3_Getchar function, where must be the ACK message generated by the camera, to clear this queue and thus completed the function. Here is the complete CameraSet function:

```
void CameraSet (char RegNum, char RegValH, char RegValL)
{
    int f;
    UART3_Sendchar(0x10);
    Delay(300);

    UART3_Sendchar(RegNum);
    Delay(300);
    if (RegValH != 0)
    {
        UART3_Sendchar(RegValH);
        Delay(300);
    }
    UART3_Sendchar(RegValL);
    Delay(300);
    f = UART3_Getchar;
    f = UART3_Getchar;
}
```

Finally, the function to set the registers of the camera is completed, so this process can start, but first, the previous initialization has to be done. The program that is going to be done now is to configure the camera and check if it works, showing the received data from the camera in the hyper terminal, as the treated characters are shown in the USB program for exchange data. So the same process for initialize the program is used, with the USBInit, the pointer to the descriptor of the USB device, the register of the handlers for the endpoints, frame interruptions and class request, the enable of the NAK interruptions in

the incoming transactions, the VCOM_init and the final connection of the USB with the USBHwConnect function. As soon as this part is finished, starts the configuration of the camera. The first part is initializing the UART connection for the LPC1758, in this case with the UART3 interface, to establish communication with the camera. The initialization is done with the function UART3_Init and the baud rate is set to 19200 bps, which is the default baud rate of the camera. Now, the connection is realized, and the sending of data from the microcontroller to the camera can start. As is said in the datasheet, the first command is the “Check Device” command, sending the value 0xEA. This is done with the function UART3_Sendchar and then, the camera has to send back to the microcontroller the ACK “TrackingV01”, as a signal of the start of the camera. It is easy to check that the mentioned message is received, just every character over the UART3 have to be read, with the UART3_Getchar function, stored in variables and shown these variables in the hyper terminal with the VCOM_putchar function. But that cannot be done in the main program, only as a prove. So to remove the “TrackingV01” message from the receive FIFO queue, a loop is made, that will not end until the last character of the sentence is read, the “1”, which is a 49 in ASCII terms:

```
UART3_Sendchar(0xEA);
h = UART3_Getchar();
while (h != 49)
{
    h = UART3_Getchar();
}
```

When the ACK from the PAC7001 is received, the program can continue with the set of the registers described in the section about the camera. As it was said previously, with the CameraSet function, the number of the register has to be introduced as an input variable, as well as the value wanted to be introduced on the register. The configuration of the registers starts with the Gain1 and Gain2, and first they are set to 10 and 0 respectively. Then come the LPF and the Ny registers, which are programmed with the values 118 and 1, as recommend the datasheet. After that, the register 0x1E (Np_H) is set to 0 and the register 0x1F (Np_L) to 3. The datasheet said that the register 0x02 must be set to 1 for sensor register update after the registers 0x00, 0x01, 0x03, 0x04, 0x1E or 0x1F have changed, and these registers are which have just been configured, so now the register 0x02 is put to 1. The registers IW and IH have two value bytes, and they are set to the maximum value permitted, 1024 for the IW register, which is 0x04 for the high byte and 0x00 for the low, and 768 for the IH register, 0x03 for the high byte and 0x00 for the low one, and they meet the requirement of IW:IH = 4:3. Continuing with the registers and following the datasheet, the value 0x88 is introduced to the register 0x07, to put the threshold mode in automatic and set it without dummy data, and the Threshold register is set, which value register is 0x08, to 40, as is recommended. In the register 0x0E, the set value is 0, which means there is no assignment mode, and for the selection of the objects

features to receive, the 0x0F register is used. It is set to 0x93, so the reception of the frame header, the object size, the object center Y and the object center X is enabled. In Table 7 is present the Register 0x0F and the meaning of its bits.

Register 0x0F (1Byte), Feature Option Enable Flag (0:Disable, 1:Enable)
Bit7: Frame Header
Bit6: Object Aspect ratio
Bit5: Object Orientation
Bit4: object Size
Bit3: Object Border Y
Bit2: Object Border X
Bit1: Object Center Y
Bit0: Object Center X

Table 7: 0x0F register of the camera: select the features to receive

The register 0x10 determines the number of tracking objects. In the case of the Head Tracking System, 4 benchmarks are needed, 4 points with which calculate the position of the camera with the POSIT algorithm, so the value of this register must be 4. Then the 0x16 register is set to 0 and the 0x1A register to 50, as is recommended for the frame brightness low bound. The register 0x1B refers to the Object Area Low Bound (OALB), where, if the camera detected an object but his size is under the defined OLAB, the PAC7001 will ignore it and will not output the features of this object. If this value is set too large, an object will be easily ignored operating at a long distance, but if the value is too small, less than 3, the accuracy will be lost when interpolating higher coordinate resolution (1024x768) and the noise will be easily came in. The suggested value in the datasheet is 3, so this value is the used one.

Finally, the registers setting is finished, but once this was done and the entire program was completed, nothing is received from the camera; there were not features of the objects in the hyper terminal. That was because of the baud rate. At first the baud rate was very low, to configure the registers of the camera, but to the outputting of the features of four objects and the collecting of them by the LPC1758, a higher baud rate is needed. So, afterwards setting the register 0x1B, the register 0x11 has to be set, because this register controls the baud rate. After several tests with different baud rates, finally is prove that the best value for it is 115200bps, which corresponds with the value 5 of the register 0x11, so this value is introduced to the register. For the proper operation of the connection between camera and microcontroller, the UART3 of the LPC1758 has to be re-initialized, but with the new baud rate value. Once the baud rate is set correctly, the camera has to be changed from the "Initial mode" to de "Operation mode", to start with the output of the objects features. To do this, with the function UART3_Sendchar the value 0x8D is sent to

the camera. In this mode, the registers cannot be changed and the camera starts to “produce” the features of the objects that it captures.

The process which corresponds with the Initial mode and the configuration of the camera registers is ended, now starts the Operation mode part, with the collection of data from the objects, the adequate treatment of them and their shown in the hyper terminal. First, two pointers are declared, pointing to a buffer; one of these pointers is pbGet and the other pbPut. In this buffer the collected data from the camera will be stored, with the pbPut pointer go over the buffer and saving the data coming from the camera on it and the pbGet pointer taking this data to showing it in the hyper terminal. Apart from these pointers, a structure is declared to store the features of the detected objects when they have been selected and identified from the buffer. This structure contains all the types of features that the camera could send of each object. As the camera will send information of four different objects, four of these structures are needed, which will be saved in an array of four elements called “Data”. The structure is:

```
typedef struct {  
    U16 BX;  
    U16 BY;  
    U16 Size;  
    U8 FlagByte;  
    U8 ObFgBy;  
    U8 EOB;  
  
} obj;
```

These components of the structures in each one of the four elements of the array “Data” have to be initialized. This is just put their values equal to 0, and this is done with the function DataInit, putting the “Data” array as input of the function. After this is done, an infinite loop is started with the instruction “while (1)” and inside this loop, all the treatments that the data need are done, from the collection of them from the camera to the final display of them in the hyper terminal.

The first step is filling the previously mentioned buffer through the pbPut pointer. The first value output from the camera is assigned to the pointer, with the function UART3_Getchar, so that in the first position of the buffer that value is stores, and then the pointer is advanced one position, to point to the next position of the buffer. This process is done continuously until the buffer is empty, whose size is 64, so it stop when pbPut reach the position 64 of the buffer. When it happens, pbPut has to be initialized to the first position of the buffer and start working with the data from the buffer. At the time to work with the buffer, the beginning of the group of data that forms the features of the four objects has to be identified. It is easy to think that now it starts at the first position of the buffer, but it is necessary to deal with cases in general, where the buffer can start to store the data from the middle of the group of data, from the features of the third object, for example. The header is the key. Searching the header in the buffer, the group of data will be found in

order, first the features of the first object, then the features of the second, of the third and finally of the fourth object, so the header has to be localized. It is known that the header is composed by four bytes, which are 0xFF, 0x00, 0xFF and 0xFF, in that order, so this succession of bytes has to be found to localize the features of the four objects in order. For doing that, a variable is declared and equated to the pbGet pointer, to go with it across the buffer which contains the data from the camera, in search of the header. In a “While” loop, this variable is compared with 255, the decimal value of 0xFF, the variable pointer is advanced, the new value is compared with 0, from 0x00, advanced it again, compared with 255 and so on, until these four values are found followed, and then is when the loop is left. Once the header is located, as the program is for general cases, the buffer has to be checked to see if all the wanted information, with the data from the four objects, is on it. The size of the buffer is 64, and each object has 9 bytes of information, with the header are 40 bytes that must be together. The pbGet pointer is pointing to the first byte of the header after the search of the succession, so the current position of the pointer plus 40 is compared with the 64 bytes of size of the buffer, to check that everything is in the buffer. Now that is sure that the features of the objects are all followed and together in the buffer, starts their identification, recognition of what type of feature is. In the datasheet is shown the order in which the camera output the information of each object, and it is collected in Table 8:

Received Bytes from the camera in order of arrival
Flag Byte
Object Flag Byte
X (High Byte)
X (Low Byte)
Y (High Byte)
Y (Low Byte)
Size (High Byte)
Size (Low Byte)
EOB

Table 8: Order of arrival of bytes from the camera

As the sequence of arrival is known, the data is going to be identified and stored as it is needed. To do that, there is the ProcessData function. In this function, the mentioned “Data” array and the pbGet pointer are introduced as input variables where, as it was said, pbGet is pointing to the first byte of the localized header in the buffer. Inside the function, the first step is to remove the bytes of the header and advance along the buffer, until the pointer is on the first byte of information of the first object. In this moment, a loop is started to take every feature of each object and put it in the Data array, each object in one of the elements of the array and every type of characteristics in their corresponding variables of

the structures, in each element of the array. So the loop goes from 1 to 4, going through the elements of the “Data” array and, following the order of arrival, storing the features in the correct variable and advancing through the buffer. The complete ProcessData function is the following:

```
void ProcessData(obj *object, unsigned char *buffer)
{
    unsigned char *tmp;

    tmp = buffer;

    head[0] = *(tmp++);
    head[1] = *(tmp++);
    head[2] = *(tmp++);
    head[3] = *(tmp++);

    for( j=0; j<4 ; j++)
    {
        object[j].FlagByte = *(tmp++);
        object[j].ObFgBy = *(tmp++);
        object[j].BX = (*(tmp++) << 8);
        object[j].BX |= *(tmp++);
        object[j].BY = (*(tmp++) << 8);
        object[j].BY |= *(tmp++);
        object[j].Size = *(tmp++) << 8;
        object[j].Size |= *(tmp++);

        object[j].EOB |= *(tmp++);
    }
}
```

Now the characteristics of the objects are correctly localized and stored, if the user wants to see them, just have to show them in the hyper terminal with the function VCOM_putchar, but have to treat the stored data.

The data containing in the variables in each element of the “Data” array are represented in decimal code, and it needed to be translated into hexadecimal code to a better presentation and interpretation of the information. To do this, the TreatData function is used, with the byte of data to treat as input variable. In the function, first the bits from 7 to 4 of the byte are taken and transformed into hexadecimal value, and then the same is done with the bits from 3 to 0 of the byte. The process is the following:

```
void TreatData (unsigned char x)
{
    unsigned char b = x >> 4;
    VCOM_putchar(b + ((b < 10) ? '0':('A'-10)));
    b = x & 15;
    VCOM_putchar(b + ((b < 10) ? '0':('A'-10)));
}
```

With this method, if the numbers are bigger than 9, which are letters in hexadecimal code, the corresponding letter is shown in the hyper terminal, with the ASCII code. This function is applied to every byte of data that is wanted to be shown with the VCOM_putchar. How to display the data in the hyper terminal can be easily modified and, in this case, the features are shown separated between them with a space, and one object per line, so there are rows of objects and columns of features.

Before the loop of the program is finish, the pgGet pointer has to be reinitialized, pointing again to the first element of the buffer, so the process of filling the buffer and taking the wanted data can be started again.

5.4.1 Camera Test-Program: Obtained Data.

The program that can communicate with the PAC7001 camera and show in the hyper terminal the data outputting by the camera is built. First of all, a capture of the data is exposed in Figure 19, with the features of the objects captured by the camera, and they are going to be analyzed, to understand what they mean:

```

BX    BY    EO FB OF SZ
0467 0153 6F B6 01 060D
0218 021D 1F B6 01 0544
0434 0370 BF B6 01 0531
0156 041B 8F B6 00 0550

BX    BY    EO FB OF SZ
0467 0153 6F B9 01 060E
0218 021C 1F B9 01 0547
0434 0370 BF B9 01 052F
0156 041B 8F B9 00 054D

BX    BY    EO FB OF SZ
0467 0153 6F BB 01 0608
0218 021C 1F BB 01 0542
0434 0371 BF BB 01 052E
0156 041A 8F BB 00 054E

```

Figure 19: Example of data from the camera in the hyper terminal

Here there are three blocks of the data sent by the camera, represented in the hyper terminal, with hexadecimal numbers and distributed in columns of coordinate X (BX), coordinate Y (BY), EOB (EO), Flag Byte (FB), Object Flag Byte (OF) and Size (SZ) of each one of the objects captured by the camera, which are every row. The BX values must be between 0 and 1024 in decimal numbers, and the BY value between 0 and 768. It is noticed that, for example, 467 in hexadecimal is 1127 in decimal, or that 41B is 1051, which are greater than 1024 and 768 respectively. This problem is tried to be solved

discovering the reason of this behavior of the values for BX and BY, and a sweep is done with a light from the beginning to the end of both X and Y axis of the field of view of the camera, to see the variation of the X and Y coordinates. Finally, is figured out that the most representative bit of the low byte of X and Y is always set to 0, never change and it is not taken into account in the final values of X and Y, so there are some “jumps” that have to be fixed later in the program, for a proper operation. That is the reason of this high values for the X and Y coordinates in this capture.

In the Flag Byte field (FB) is represented the number of frame and if the object is found, if the camera can capture the correspond object. The bit 7 is always 1, the 6 and 5 represent the capture of the objet (01) or not (00) and the rest of bits represent the frame number. It is seen that all the objects of the same frame have the same FB byte, and the following frames have not continue the progression of numbers because during the treatment of data, or because one frame is not completely in the buffer, frames are lost in the middle.

With the Object Flag, the shape of the object can be known, and if the frame is finished or not. The bit 7 is always 0 and bits 3 and 2 represent the shape of the object: 00 means circle object, 01 bar object, 10 circle-hole object and 11 bar-hole object. In this case, there are circle objects. The last bit represent if the frame is finish, 1 says not and 0 says yes, and as is seen, in the first 3 objects is represented that the frame is not finish, and the last one has a 0 in their last bit, which means the frame is finished. The rest of bits are reserved.

Now this data will be seen changing the registers of Gain 1 and Gain 2, which are previously set to 10 and 0 respectively, to test which combination is better in matter of distance of the camera from the set of LEDs and better reception of the four objects. To do these checking, the camera is placed at a height of 7.5cm, 4 cm displaced from one side of the set of LEDs and pointing to this set, so the camera is put more or less focusing at the center of the triangular prism that form the set. The measure starts with the camera at 5 cm from the front side of the prism and it will be distanced 5 cm by 5 cm, searching to receive all the objects and finished when it cannot be possible.

The maximum value for the Gain 1 is 15 and for Gain 2 is 31. The comparisons start with the pair Gain1=10, Gain2=0, the recommended value in the datasheet, and then these values will be varied:

1) Gain1 = 10, Gain2 = 0.

Distance of the camera: 5 cm

```
BX  BY  E0 FB OF SZ
0173 0165 6F AA 01 0528
062F 0478 1F AA 01 0577
0000 0000 BF 8A 01 0000
0000 0000 0F 8A 00 0000
```

```
BX  BY  E0 FB OF SZ
0173 0165 6F AD 01 052B
062F 0478 1F AD 01 0577
0000 0000 BF 8D 01 0000
0000 0000 0F 8D 00 0000
```

```
BX  BY  E0 FB OF SZ
0173 0165 6F B0 01 052A
062F 0478 1F B0 01 0579
0000 0000 BF 90 01 0000
0000 0000 0F 90 00 0000
```

Distance of the camera: 10 cm

```
BX  BY  E0 FB OF SZ
061A 005E 6F B5 01 0575
017C 020C 1F B5 01 047D
051B 043E BF B5 01 0507
0042 052B 0F B5 00 0312
```

```
BX  BY  E0 FB OF SZ
061A 005F 6F B8 01 0573
017C 020C 1F B8 01 047D
051B 043E BF B8 01 0507
0041 052B 0F B8 00 0311
```

```
BX  BY  E0 FB OF SZ
061A 005F 6F BA 01 0572
017C 020C 1F BA 01 047F
051A 043E BF BA 01 0505
0041 052B 0F BA 00 0311
```

At a distance of 5cm the camera can only capture 2 objects, but when the distance is 10cm the four objects can be captured by the camera.

Distance of the camera: 15cm

```
BX  BY  E0 FB OF SZ
0521 014A 6F B2 01 0533
0217 0234 1F B2 01 045D
046B 0429 BF B2 01 045C
0120 0475 0F B2 00 0452
```

```
BX  BY  E0 FB OF SZ
0521 014A 6F B5 01 0533
0217 0234 1F B5 01 045F
046B 0429 BF B5 01 045C
0120 0475 0F B5 00 0453
```

```
BX  BY  E0 FB OF SZ
0521 014A 6F B8 01 0538
0217 0234 1F B8 01 0460
046B 0429 BF B8 01 045C
0120 0475 0F B8 00 0452
```

Distance of the camera: 20 cm

```
BX  BY  E0 FB OF SZ
0506 020E 6F B5 01 0507
024D 0250 1F B5 01 0441
0466 0421 BF B5 01 0437
017E 044A 0F B5 00 043D
```

```
BX  BY  E0 FB OF SZ
0506 020E 6F B8 01 0507
024D 0250 1F B8 01 0442
0466 0420 BF B8 01 0435
017E 044A 0F B8 00 043C
```

```
BX  BY  E0 FB OF SZ
0506 020E 6F BA 01 0506
024D 024F 1F BA 01 0440
0466 0420 BF BA 01 0436
017E 044A 0F BA 00 043D
```

In both cases the four objects still appears in the data from the camera show at the hyper terminal.

Distance from the camera: 20cm

BX	BY	EO	FB	OF	SZ
0506	020E	6F	B5	01	0507
024D	0250	1F	B5	01	0441
0466	0421	BF	B5	01	0437
017E	044A	0F	B5	00	043D

BX	BY	EO	FB	OF	SZ
0506	020E	6F	B8	01	0507
024D	0250	1F	B8	01	0442
0466	0420	BF	B8	01	0435
017E	044A	0F	B8	00	043C

BX	BY	EO	FB	OF	SZ
0506	020E	6F	BA	01	0506
024D	024F	1F	BA	01	0440
0466	0420	BF	BA	01	0436
017E	044A	0F	BA	00	043D

Distance from the camera: 25cm

BX	BY	EO	FB	OF	SZ
0503	0249	6F	B2	01	0900
025E	0357	1F	B2	01	083B
0000	0000	BF	92	01	0000
0000	0000	0F	92	00	0000

BX	BY	EO	FB	OF	SZ
0503	024A	6F	B5	01	087D
025E	0355	1F	B5	01	0842
0000	0000	BF	95	01	0000
0000	0000	0F	95	00	0000

BX	BY	EO	FB	OF	SZ
0503	0249	6F	B8	01	087C
025E	0354	1F	B8	01	0844
0000	0000	BF	98	01	0000
0000	0000	0F	98	00	0000

It is seen that in one point between 20 and 25cm the camera lost the vision of two of the objects.

With these values in the Gain1 and Gain2 registers, the camera works well between 10 and 20 cm from the set of LEDs.

2) Gain1 = 10, Gain2 = 15.

Distance from the camera: 5cm

BX	BY	EO	FB	OF	SZ
0024	0133	6F	B6	01	0247
050E	046C	DF	B6	01	0665
0000	0000	FF	96	01	0000
0000	0000	0F	96	00	0000

BX	BY	EO	FB	OF	SZ
0025	0132	6F	B9	01	0262
050D	046A	DF	B9	01	061B
0000	0000	FF	99	01	0000
0000	0000	0F	99	00	0000

BX	BY	EO	FB	OF	SZ
0024	0133	6F	BB	01	0242
050D	046A	DF	BB	01	061D
0000	0000	FF	9B	01	0000
0000	0000	0F	9B	00	0000

Distance from the camera: 10cm

BX	BY	EO	FB	OF	SZ
062D	004D	6F	B9	01	0778
012B	0176	DF	B9	01	0469
0501	0432	FF	B9	01	045F
0021	0555	0F	B9	00	007F

BX	BY	EO	FB	OF	SZ
062B	004D	6F	BB	01	072D
012B	0176	DF	BB	01	0466
0501	0432	FF	BB	01	045B
0021	0555	0F	BB	00	007F

BX	BY	EO	FB	OF	SZ
062C	004E	6F	BE	01	0752
012B	0176	DF	BE	01	046E
0502	0432	FF	BE	01	0520
0023	0554	0F	BE	00	0115

The four objects appear in a point close to 10cm of distance from the set of LEDs to the camera.

Distance from the camera: 15cm

BX	BY	EO	FB	OF	SZ
075D	0014	6F	BB	01	0028
0615	014B	DF	BB	01	090F
0238	022C	FF	BB	01	042B
0000	0000	0F	9B	00	0000

BX	BY	EO	FB	OF	SZ
061B	0147	6F	BE	01	0941
0238	022B	DF	BE	01	042D
0518	042C	FF	BE	01	042D
0000	0000	0F	9E	00	0000

BX	BY	EO	FB	OF	SZ
061C	0146	6F	A1	01	095A
0237	022B	DF	A1	01	042D
0518	042C	FF	A1	01	041E
0000	0000	0F	81	00	0000

Distance from the camera: 20cm

BX	BY	EO	FB	OF	SZ
053F	0161	6F	B9	01	0922
0240	022A	DF	B9	01	037C
0463	037C	FF	B9	01	040B
0000	0000	0F	99	00	0000

BX	BY	EO	FB	OF	SZ
053D	0162	6F	BB	01	084B
0240	022A	DF	BB	01	0379
0463	037C	FF	BB	01	040F
0000	0000	0F	9B	00	0000

BX	BY	EO	FB	OF	SZ
053E	0162	6F	BE	01	0876
0240	022A	DF	BE	01	037B
0463	037C	FF	BE	01	040B
0000	0000	0F	9E	00	0000

The camera starts to fail and just can capture 3 objects at these distances, so is not needed to check more

The proper distance for this value of the Gain1 and Gain2 is around 10 cm, what is not good for the wanted purpose.

3) Gain1 = 10, Gain2 = 31

Distance from the camera: 5cm

BX	BY	EO	FB	OF	SZ
0059	011A	7F	BA	01	0631
054C	0443	1F	BA	01	077B
0000	0000	AF	9A	01	0000
0000	0000	0F	9A	00	0000

BX	BY	EO	FB	OF	SZ
0059	0116	7F	BD	01	0659
054E	0441	1F	BD	01	0952
0000	0000	AF	9D	01	0000
0000	0000	0F	9D	00	0000

BX	BY	EO	FB	OF	SZ
0059	0117	7F	BF	01	0659
054D	0441	1F	BF	01	087E
0000	0000	AF	9F	01	0000
0000	0000	0F	9F	00	0000

Distance from the camera: 10cm

BX	BY	EO	FB	OF	SZ
0659	005B	7F	A7	01	0915
0163	0165	1F	A7	01	0528
0523	0425	AF	A7	01	057A
0050	052F	0F	A7	00	037A

BX	BY	EO	FB	OF	SZ
0658	005C	7F	AA	01	092C
0163	0164	1F	AA	01	053E
0523	0425	AF	AA	01	057F
0050	052E	0F	AA	00	037B

BX	BY	EO	FB	OF	SZ
0659	005F	7F	AD	01	096B
0163	0164	1F	AD	01	055D
0523	0425	AF	AD	01	060C
0050	052E	0F	AD	00	0379

At around 10cm of distance between the camera and the LEDs the features of the four wanted objects are started to be seen in the hyper terminal.

Distance from the camera: 15cm

BX	BY	E0	FB	OF	SZ
063B	012F	7F	A7	01	0D36
0173	006D	1F	A7	01	0004
0225	021B	AF	A7	01	0459
0000	0000	0F	87	00	0000

BX	BY	E0	FB	OF	SZ
063F	0132	7F	AA	01	0E45
0173	0109	1F	AA	05	000A
0226	021C	AF	AA	01	0468
0000	0000	0F	8A	00	0000

BX	BY	E0	FB	OF	SZ
063C	012F	7F	AD	01	0D51
0179	010F	1F	AD	05	0016
0225	021B	AF	AD	01	045E
0000	0000	0F	8D	00	0000

Distance from the camera: 20cm

BX	BY	E0	FB	OF	SZ
0474	026F	7F	AF	01	0E55
0248	032D	1F	AF	01	0820
0000	0000	AF	8F	01	0000
0000	0000	0F	8F	00	0000

BX	BY	E0	FB	OF	SZ
0476	026F	7F	B2	01	0E30
0249	032D	1F	B2	01	0820
0000	0000	AF	92	01	0000
0000	0000	0F	92	00	0000

BX	BY	E0	FB	OF	SZ
047C	0268	7F	B5	01	105E
0249	032C	1F	B5	01	082A
0000	0000	AF	95	01	0000
0000	0000	0F	95	00	0000

The camera starts to fail early and now it is impossible to capture the four needed objects, so the collection of data stops.

As the previous case, for Gain1= 10 and Gain2= 31 the distance must be around 10cm.

4) Gain1 = 15, Gain2 = 0:

Distance from the camera: 5cm

BX	BY	E0	FB	OF	SZ
005F	014B	6F	B0	01	0515
0535	0453	DF	B0	01	0568
0000	0000	AF	90	01	0000
0000	0000	0F	90	00	0000

BX	BY	E0	FB	OF	SZ
005F	014B	6F	B3	01	0514
0535	0453	DF	B3	01	056A
0000	0000	AF	93	01	0000
0000	0000	0F	93	00	0000

BX	BY	E0	FB	OF	SZ
005F	014C	6F	B6	01	0513
0536	0452	DF	B6	01	0568
0000	0000	AF	96	01	0000
0000	0000	0F	96	00	0000

Distance from the camera: 10cm

BX	BY	E0	FB	OF	SZ
062A	0058	6F	B8	01	0571
020B	0207	DF	B8	01	0510
0528	043A	AF	B8	01	051B
004B	0522	0F	B8	00	0372

BX	BY	E0	FB	OF	SZ
062A	0058	6F	BB	01	057B
020B	0208	DF	BB	01	0512
0528	043A	AF	BB	01	051D
004B	0522	0F	BB	00	0371

BX	BY	E0	FB	OF	SZ
0629	0059	6F	BE	01	057B
020B	0208	DF	BE	01	0515
0528	043A	AF	BE	01	051B
004B	0522	0F	BE	00	036F

The features of four objects appear in the hyper terminal when the camera is at 10cm from the LEDs.

Distance from the camera: 15cm

BX	BY	E0	FB	OF	SZ
0510	013A	6F	A8	01	054E
020D	023C	DF	A8	01	046E
046C	041E	AF	A8	01	046B
0124	0500	0F	A8	00	046A

BX	BY	E0	FB	OF	SZ
0510	013A	6F	AB	01	054D
020D	023C	DF	AB	01	046E
046C	041E	AF	AB	01	046A
0124	0500	0F	AB	00	0469

BX	BY	E0	FB	OF	SZ
0510	013A	6F	AE	01	054D
020D	023C	DF	AE	01	046E
046C	041E	AF	AE	01	046A
0124	0500	0F	AE	00	0469

Distance from the camera: 20cm

BX	BY	E0	FB	OF	SZ
044E	0206	6F	BE	01	051E
021A	0249	DF	BE	01	0450
0436	040F	AF	BE	01	044B
0153	0449	0F	BE	00	0441

BX	BY	E0	FB	OF	SZ
044E	0206	6F	A0	01	0515
021A	0249	DF	A0	01	044E
0437	040E	AF	A0	01	044C
0153	0449	0F	A0	00	0441

BX	BY	E0	FB	OF	SZ
044E	0206	6F	A3	01	051B
021A	0249	DF	A3	01	044F
0437	040F	AF	A3	01	044B
0153	0449	0F	A3	00	0440

Now at these distances, is still seeing in the hyper terminal the features of the four LEDs captured by the camera

Distance from the camera: 25cm

BX	BY	E0	FB	OF	SZ
0476	0254	6F	BE	01	092D
0263	034E	DF	BE	01	085E
0000	0000	AF	9E	01	0000
0000	0000	0F	9E	00	0000

BX	BY	E0	FB	OF	SZ
0476	0254	6F	A0	01	092C
0262	0351	DF	A0	01	085C
0000	0000	AF	80	01	0000
0000	0000	0F	80	00	0000

BX	BY	E0	FB	OF	SZ
0476	0254	6F	A3	01	092B
0262	0351	DF	A3	01	085D
0000	0000	AF	83	01	0000
0000	0000	0F	83	00	0000

In a distance between 20 and 25cm, the receiving of the features of two of the objects stops, so the measure stops too.

In this case of configuration of the Gain1 and Gain2 registers, a valid range is obtained from 10 to a bit more than 20cm.

5) Gain1 = 15, Gain2 = 15.

Distance from the camera: 5cm

BX	BY	EO	FB	OF	SZ
0074	016C	7F	B6	01	0700
0538	0479	9F	B6	01	0716
0000	0000	BF	96	01	0000
0000	0000	0F	96	00	0000

BX	BY	EO	FB	OF	SZ
0075	016A	7F	B8	01	064A
0538	0479	9F	B8	01	0729
0000	0000	BF	98	01	0000
0000	0000	0F	98	00	0000

BX	BY	EO	FB	OF	SZ
0074	016A	7F	BB	01	0664
053A	047A	9F	BB	01	0759
0000	0000	BF	9B	01	0000
0000	0000	0F	9B	00	0000

Distance from the camera: 10cm

BX	BY	EO	FB	OF	SZ
057D	0069	7F	BB	01	0B0C
016F	001F	9F	BB	05	000E
015E	0222	BF	BB	01	057F
0509	0444	0F	BB	00	0644

BX	BY	EO	FB	OF	SZ
0578	006C	7F	BE	01	0A3A
0163	0011	9F	BE	05	000A
015E	0221	BF	BE	01	0604
0509	0446	0F	BE	00	0621

BX	BY	EO	FB	OF	SZ
0577	006B	7F	A0	01	0A31
0168	0011	9F	A0	05	0009
015E	0221	BF	A0	01	0576
0508	0446	0F	A0	00	061F

It is seen again that the reception of four objects starts at a distance of 10cm.

Distance from the camera: 15cm

BX	BY	EO	FB	OF	SZ
073E	001F	7F	B0	01	002F
0567	017C	9F	B0	01	0C40
0250	0252	BF	B0	01	0564
0000	0000	0F	90	00	0000

BX	BY	EO	FB	OF	SZ
0740	001D	7F	B3	01	0040
0569	017A	9F	B3	01	0D0F
0250	0252	BF	B3	01	0564
0000	0000	0F	93	00	0000

BX	BY	EO	FB	OF	SZ
073E	001F	7F	B6	01	002F
056E	017C	9F	B6	01	0D69
0250	0252	BF	B6	01	056F
0000	0000	0F	96	00	0000

Distance from the camera: 20cm

BX	BY	EO	FB	OF	SZ
0543	020B	7F	B8	01	0951
0268	0345	9F	B8	01	0B04
0514	0410	BF	B8	01	053F
0000	0000	0F	98	00	0000

BX	BY	EO	FB	OF	SZ
0545	020C	7F	BB	01	0978
0269	0344	9F	BB	01	0B00
0514	0410	BF	BB	01	0541
0000	0000	0F	9B	00	0000

BX	BY	EO	FB	OF	SZ
0548	020A	7F	BE	01	0A45
0268	0344	9F	BE	01	0B0F
0514	0410	BF	BE	01	0543
0000	0000	0F	9E	00	0000

It is observed that the features of four objects cannot be received, so the collection of data stops.

As other cases, the system with the registers set in that way could only work with a distance between LEDs and camera of about 10cm

6) Gain1 = 15, Gain2 = 31.

Distance from the camera: 5cm

BX	BY	EO	FB	OF	SZ
0074	016C	7F	B6	01	0700
0538	0479	9F	B6	01	0716
0000	0000	BF	96	01	0000
0000	0000	0F	96	00	0000

BX	BY	EO	FB	OF	SZ
0075	016A	7F	B8	01	064A
0538	0479	9F	B8	01	0729
0000	0000	BF	98	01	0000
0000	0000	0F	98	00	0000

BX	BY	EO	FB	OF	SZ
0074	016A	7F	BB	01	0664
053A	047A	9F	BB	01	0759
0000	0000	BF	9B	01	0000
0000	0000	0F	9B	00	0000

Distance from the camera:

BX	BY	EO	FB	OF	SZ
057D	0069	7F	BB	01	0B0C
016F	001F	9F	BB	05	000E
015E	0222	BF	BB	01	057F
0509	0444	0F	BB	00	0644

BX	BY	EO	FB	OF	SZ
0578	006C	7F	BE	01	0A3A
0163	0011	9F	BE	05	000A
015E	0221	BF	BE	01	0604
0509	0446	0F	BE	00	0621

BX	BY	EO	FB	OF	SZ
0577	006B	7F	A0	01	0A31
0168	0011	9F	A0	05	0009
015E	0221	BF	A0	01	0576
0508	0446	0F	A0	00	061F

The wanted reception in the hyper terminal of four objects starts with a distance around 10cm between camera and LEDs.

Distance from the camera: 15cm

BX	BY	EO	FB	OF	SZ
073E	001F	7F	B0	01	002F
0567	017C	9F	B0	01	0C40
0250	0252	BF	B0	01	0564
0000	0000	0F	90	00	0000

BX	BY	EO	FB	OF	SZ
0740	001D	7F	B3	01	0040
0569	017A	9F	B3	01	0D0F
0250	0252	BF	B3	01	0564
0000	0000	0F	93	00	0000

BX	BY	EO	FB	OF	SZ
073E	001F	7F	B6	01	002F
056E	017C	9F	B6	01	0D69
0250	0252	BF	B6	01	056F
0000	0000	0F	96	00	0000

Distance from the camera: 20cm

BX	BY	EO	FB	OF	SZ
0543	020B	7F	B8	01	0951
0268	0345	9F	B8	01	0B04
0514	0410	BF	B8	01	053F
0000	0000	0F	98	00	0000

BX	BY	EO	FB	OF	SZ
0545	020C	7F	BB	01	0978
0269	0344	9F	BB	01	0B00
0514	0410	BF	BB	01	0541
0000	0000	0F	9B	00	0000

BX	BY	EO	FB	OF	SZ
0548	020A	7F	BE	01	0A45
0268	0344	9F	BE	01	0B0F
0514	0410	BF	BE	01	0543
0000	0000	0F	9E	00	0000

It is seen that, like in other cases, at these distances the reception of four objects starts to fail.

The distance between the PAC7001 and the LEDs with this configuration cannot be more than 10cm.

In Table 9 all the results of the measurements are collected:

Gain1	Gain2	Range of distances between PAC7001 and LEDs to captures 4 objects
10	0	~ 10-20 cm
10	15	~ 10 cm
10	31	~ 10 cm
15	0	~ 10-20 cm
15	15	~10 cm
15	31	~10 cm

Table 9: Distances between PAC7001 and the LEDs to capture 4 objects, according to the values of Gain1 and Gain2

With these tests it is seen that the best option for the Gain1 and Gain2 registers of the camera is set the Gain2 register to 0 and the Gain1 to 10 or 15. That gives a maximum distance between the camera and the set of LEDs a little bit more than 20cm.

It is observed that in every measure, at 5 cm the camera can only capture 2 objects, that is because of the field of view. The field of view (Figure 20) is the part of the world that is visible by the camera and, in this case, according to the datasheet, the field of view is 64 degrees in diagonal.

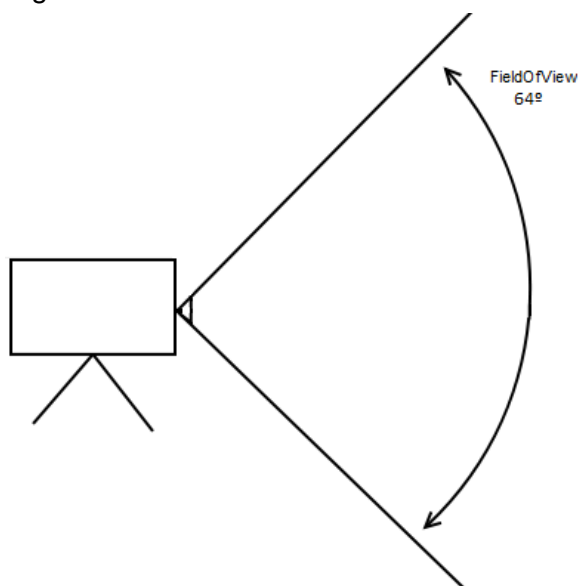


Figure 20: Field of view

With this angle, two right triangles can be formed, one upper and other lower, with a horizontal line crossing the angle and dividing it in two angles of 32 degrees. Knowing this angle and one of his sides of the right triangle, the rest of the sides can be easily obtained (Figure 21):

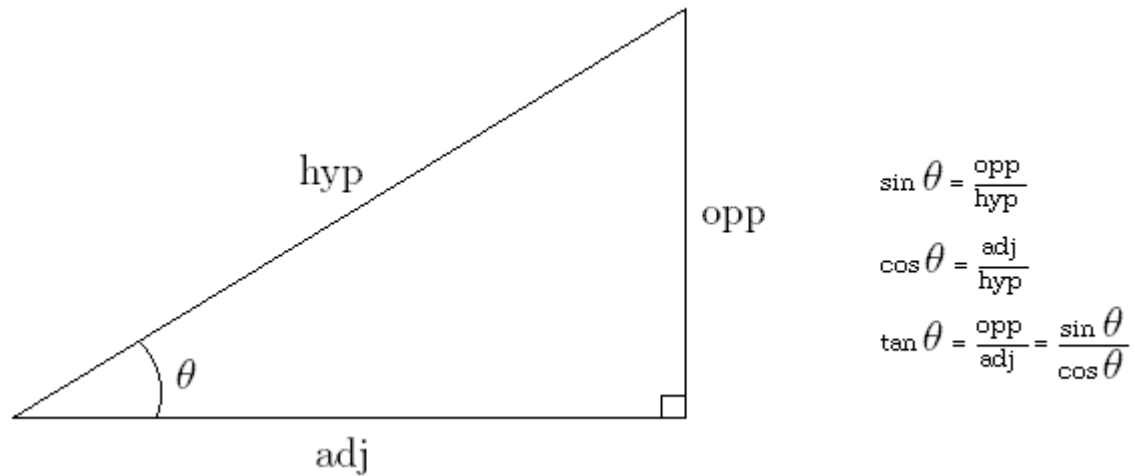


Figure 21: Right triangle and sides

There is an angle of 32 degrees and the adjacent side is 5 cm, so there is a hypotenuse of 5.89 cm and, continuing operating, an opposite side of 3.12 cm is obtained. So, being the field of view a rectangle, with 4:3 ratio (array elements 128 x 96 in the datasheet) and, as the angle of view is in diagonal, being the distance from the center of the rectangle to each of his vertex 3.12 cm, a rectangle of 4.99x3.74 is obtained. This is not compatible with the front square of the set of LEDs, which is a square of 11x8.5. However, if the same operations are done with an adjacent side of 14 cm, which is the 5 cm of distance of the camera to the LEDs plus 9 cm of depth of the prism of LEDs, a distance from the center of the rectangle to one vertex of 8.74 is obtained, which means that the rectangle is 14x10.5 which is more than the rectangle of LEDs of the back part. So these two LEDs of the back part are the objects that the camera captures.

In the case of 10 cm of distance from the camera to the LEDs, the result of the field of view of the camera is a rectangle of 10x7.5. That not fix with the fact of the four objects can be seen when the camera is at a range of 10 cm, but it is probably because of the measure is realized from the front of the camera, which is approximately at a distance of 1 cm from the sensor, plus measurement errors and a wider angle of view. For example, with this centimeter of more distance, all the LEDs can be in the field of view of the camera.

5.5 POSIT Algorithm

The program for seeing the data outputting from the camera has been seen, and now the POSIT algorithm is going to be done, to work with these data with the objective of moving the mouse pointer according to them.

The process of develop the POSIT algorithm is well explained by DeMenthon and Davis [34], which paper is collected in the appendix B, and this explanation is followed to build the POSIT program. The part of the main program which contains the POSIT algorithm has to start after the ProcessData function, after the obtaining and orderly storage of the data from the buffer. There are 6 different steps described in the mentioned study of the POSIT, the first of them is the preliminary step, which consists in writing a matrix composed by the vectors that connect a reference point with the rest of the points. In this case there are four points, four objects that the camera can capture and output their features, and these objects correspond with the four LEDs in the set of LEDs. So what it is done is select one of these LEDs as reference point, and measure the distance with the rest of the LEDs, in this manner a matrix with dimension 3x3 is obtained, where each row is the vector of this distance from the reference point to each one of the rest of LEDs. The set of LEDs is, according with the coordinate system of the camera, a rectangular prism of 11x8.5x9 cm, with the distribution of the LEDs appearing in Figure 22:

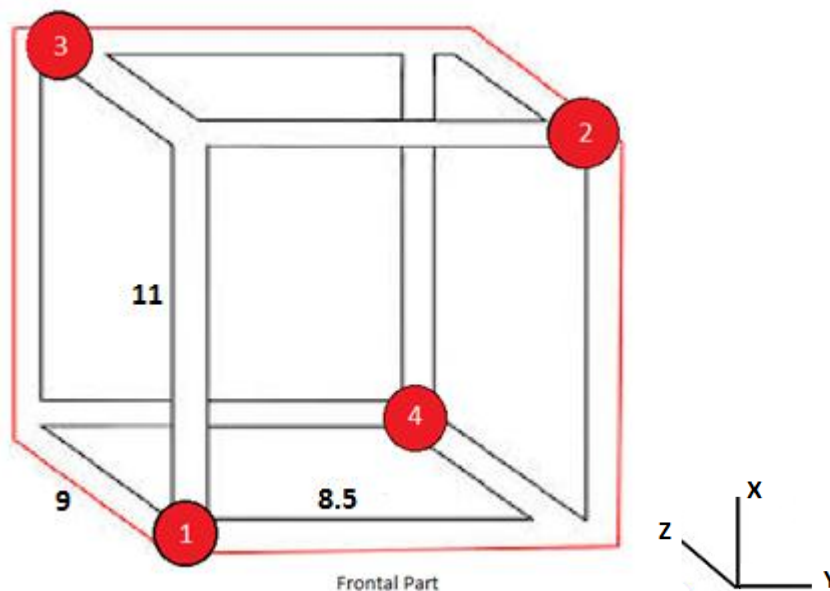


Figure 22: Set of LEDs and the position of them

The red spots are the places of the LEDs, and the LED 1 is selected as the reference point, so the distance vector to the LED 2 is (11,8.5,0), the vector to the LED 3 is (11,0,9) and the vector to the LED 4 is (0,8.5,9) and the rows of the wanted matrix, the A matrix, are:

$$A = \begin{pmatrix} 11 & 8.5 & 0 \\ 11 & 0 & 9 \\ 0 & 8.5 & 9 \end{pmatrix}$$

Once the A matrix is formed, his pseudoinverse matrix has to be taken, the B matrix. The pseudoinverse matrix equation is:

$$A^+ = (A^T A)^{-1} A^T = B \quad [3]$$

The result of that operation is

$$B = \begin{pmatrix} \frac{1}{22} & \frac{1}{22} & -\frac{1}{22} \\ \frac{1}{17} & -\frac{1}{17} & \frac{1}{17} \\ -\frac{1}{18} & \frac{1}{18} & \frac{1}{18} \end{pmatrix}$$

Once we have the two matrixes, the epsilon0 has to be initialized, as it is said in the paper. There are 3 epsilon0, as vectors in the A matrix, and they have to be equalized to 0 at the beginning of the loop of the POSIT algorithm. When this is done, first both the image vector x and image vector y have to be computed with 3 coordinates, one for each one of the objects that there are, excluding the reference object. The name for these vectors in this case is Xim and Yim, and the form of the coordinates that make them is:

$$X_{im_i} = X_i (1 + \epsilon_{0i}) - X_0 \quad Y_{im_i} = Y_i (1 + \epsilon_{0i}) - Y_0 \quad [4]$$

Where X_0 and Y_0 are the BX and BY features of the reference object and X_i and Y_i the same features of the rest of the object, with $i = \{1, 2, 3\}$ corresponding with LED 2, LED 3 and LED 4 respectively. But in this point there is a problem, because is not known to which of the four LEDs correspond the features sending by the camera as the first object, the same happened with the second, third and fourth object. So before starting with the image vectors, the data has to be identified, which of the objects outputting by the camera refers to the reference LED and which to the others, following the order shown in the cube image. For doing that, it is know that the object center coordinate resolution of the camera is max 1024*768, which means that the maximum value of the coordinates for X is 1024 and for Y 768, with a range between 0 and these numbers. So the center of the system, the point which is in the middle of the set is the point (512,384) and the coordinates for X and Y for each object captured by the camera are referred to this center. The camera always must be pointing inside the cube of LEDs, so the central point of the coordinate system must be placed somewhere between the four LEDs. In this manner, a LED is placed in each one of the quadrants of the coordinate system (Figure 23), so it will be easy to identify the quadrant and the correspondent LED:

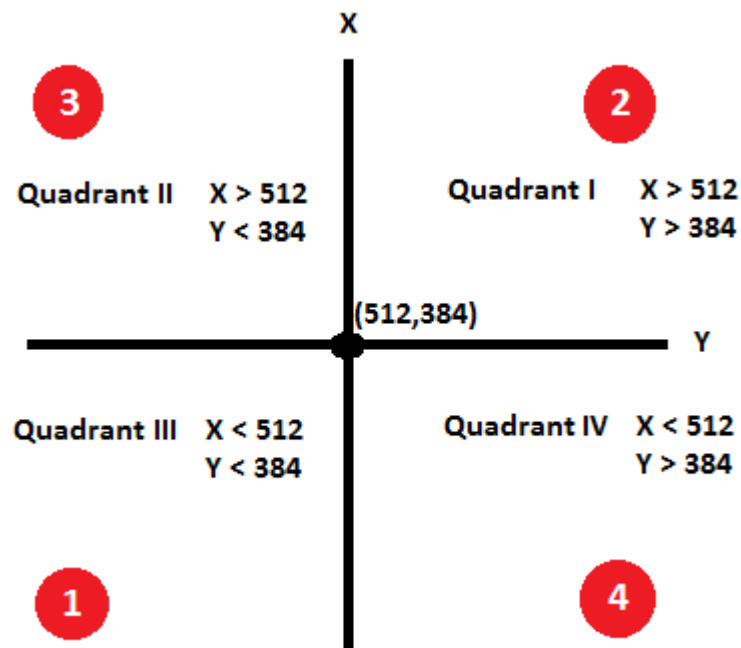


Figure 23: Quadrants in the camera's reference system and the LEDs on it

As it is shown in the picture, to identify the LED 1, the reference object, it is needed to find the object outputting from the camera which features BX and BY match with the condition described for the Quadrant III and select this object as reference. The same search for the LED 2 in the Quadrant I, the LED 3 in the Quadrant II and the LED 4 in the Quadrant IV, to maintain the order of vectors following for the matrix A. Now there is a problem with the data received as the X and Y coordinates of the different objects, as it was described previously. The most significant value of the low byte of X and Y does not change, it is always 0, and it must not be taken into account to store the value of the coordinates. So it is needed to skip it and "put together" the two resulting parts of both X and Y variables, the part of the left of the bit, and the part of the right. This is done with the following commands, obtaining the wanted and correct values in the variables Xvar and Yvar:

```
U16 Xvar = 0, Yvar = 0, a = 0, b = 0;
a = (Data[cont].BX & 127);
b = (Data[cont].BX >> 1);
Xvar = b ^ a;

a = (Data[cont].BY & 127);
b = (Data[cont].BY >> 1);
Yvar = b ^ a;
```

Finally, values for the coordinates that will be in the expected ranges are obtained; from 0 to 1024 for X coordinate and from 0 to 768 for the Y coordinate. Once the data is

treated, it can be compared to place the objects in the different quadrants and estimate which LED is the studied:

```

    for (cont=0; cont<4; cont++)
    {
        U16 Xvar = 0, Yvar = 0, a = 0, b = 0;
        a = (Data[cont].BX & 127);
        b = (Data[cont].BX >> 1);
        Xvar = b ^ a;

        a = (Data[cont].BY & 127);
        b = (Data[cont].BY >> 1);
        Yvar = b ^ a;

        while ((Xvar != 0 ) | (Yvar != 0))
        if (Xvar<= 512 ){
            if (Yvar <= 384){                // Quadrant III
                Xcenter[0] = Xvar;          // Match with LED 1, reference LED
                Ycenter[0] = Yvar;
            }
            else {                            // Quadrant VI
                Xcenter[3] = Xvar;          // Match with LED 4, third distance
                Ycenter[3] = Yvar;
            }
        }
        else {
            if (Yvar <= 384){                // Quadrant II
                Xcenter[2] = Xvar;          // Match with LED 3, second
                Ycenter[2] = Yvar;
            }
            else {                            // Quadrant I
                Xcenter[1] = Xvar;          // Match with LED 2, first distance
                Ycenter[1] = Yvar;
            }
        }
    }
}

```

It is noticed that the first two blocks of data taken from the buffer of the data from the camera have values that are different than the expected, even solving the problem of the unset bit. That causes a bad assign of objects with LEDs and it have to be solved for their later use in the POSIT algorithm. To do that, a variable controls the times that the buffer is filled with useful data, and the part of “LEDs assignments” and the POSIT algorithm are not started until this variable is greater than 2.

Once that the objects from the camera are matched with the LEDs in the way that is wanted, continues with the image vectors. There is already described the formula for the image vectors X_{im} and Y_{im} , where each term of the vector depends of the coordinates of

the reference object and the coordinates of each of the rest of the object in order, as it was described previously. To obtain the whole vectors:

$$\begin{aligned} Xim[0] &= (Xcenter[1]*(1 + epsilon0[0]) - Xcenter[0]); \\ Xim[1] &= (Xcenter[2]*(1 + epsilon0[1]) - Xcenter[0]); \\ Xim[2] &= (Xcenter[3]*(1 + epsilon0[2]) - Xcenter[0]); \end{aligned} \quad [5]$$

$$\begin{aligned} Yim[0] &= (Ycenter[1]*(1 + epsilon0[0]) - Ycenter[0]); \\ Yim[1] &= (Ycenter[2]*(1 + epsilon0[1]) - Ycenter[0]); \\ Yim[2] &= (Ycenter[3]*(1 + epsilon0[2]) - Ycenter[0]); \end{aligned} \quad [6]$$

After obtaining these image vectors Xim and Yim, they have to be multiplied by the matrix B. Multiplying B and the vector Xim a vector called I is obtained, and multiplying B and the vector Yim the result is a vector called J, both of them, of course, with 3 coordinates.

$$I = B * Xim \quad J = B * Yim \quad [7]$$

The way in that these operations are done in the program is the following:

$$\begin{aligned} I[0] &= B[0][0]*Xim[0] + B[0][1]*Xim[1] + B[0][2]*Xim[2]; \\ I[1] &= B[1][0]*Xim[0] + B[1][1]*Xim[1] + B[1][2]*Xim[2]; \\ I[2] &= B[2][0]*Xim[0] + B[2][1]*Xim[1] + B[2][2]*Xim[2]; \end{aligned} \quad [8]$$

$$\begin{aligned} J[0] &= B[0][0]*Yim[0] + B[0][1]*Yim[1] + B[0][2]*Yim[2]; \\ J[1] &= B[1][0]*Yim[0] + B[1][1]*Yim[1] + B[1][2]*Yim[2]; \\ J[2] &= B[2][0]*Yim[0] + B[2][1]*Yim[1] + B[2][2]*Yim[2]; \end{aligned} \quad [9]$$

Where can be seen how is obtained each term of the vector I and J. These vectors are necessary to get later the vectors for the rotation matrix and the scale of the projection. This scale is s and it is the result of $(s_1 + s_2)/2$, where s_1 and s_2 are:

$$\begin{aligned} s_1 &= (I \cdot I)^{1/2} & s_2 &= (J \cdot J)^{1/2} \\ s &= (s_1 + s_2)/2 \end{aligned} \quad [10]$$

So is needed to operate with the I and J vector to obtain the s_1 and s_2 factors and finally the scale of the projection:

$$\begin{aligned} s1 &= I[0]*I[0] + I[1]*I[1] + I[2]*I[2]; \\ s2 &= J[0]*J[0] + J[1]*J[1] + J[2]*J[2]; \end{aligned} \quad [11]$$

$$\begin{aligned} s1 &= \text{sqrt}(s1); \\ s2 &= \text{sqrt}(s2); \end{aligned} \quad [12]$$

$$s = (s1 + s2)/2; \quad [13]$$

Now it is time to get the i and j vectors, necessary to obtain the k vector and, with the three of them, get the rotation matrix. The i and j vectors are just the division between the coordinates of the I vector and the s_1 factor and the coordinates of the J vector and the s_2 factor respectively, and the k vector is the cross-product of these i and j vectors:

$$\begin{aligned} i[0] &= I[0]/s_1; \\ i[1] &= I[1]/s_1; \\ i[2] &= I[2]/s_1; \end{aligned} \quad [14]$$

$$\begin{aligned} j[0] &= J[0]/s_2; \\ j[1] &= J[1]/s_2; \\ j[2] &= J[2]/s_2; \end{aligned} \quad [15]$$

$$\begin{aligned} k[0] &= (i[1] * j[2]) - (i[2] * j[1]); \\ k[1] &= (i[2] * j[0]) - (i[0] * j[2]); \\ k[2] &= (i[0] * j[1]) - (i[1] * j[0]); \end{aligned} \quad [16]$$

After that, following the paper, the z coordinate of the translation vector is going to be taken. The x and the y coordinates of this vector are the x and y coordinates of the reference object, and the z coordinate is obtained dividing the camera focal length by the scale of the projection, the parameter s. In the PAC7001 camera, according to the datasheet, the focal length must be 1024, value which is stored in the variable Focal_L, and to get the z coordinate, named as Z0, it is done:

$$Z0 = \text{Focal_L}/s; \quad [17]$$

Now new epsilons have to be computed, and the vector that contains these new epsilons is called epsilon1. Each of the components of the vector is formed from the vectors of the matrix A, the vectors of distance of the LEDs with respect to the reference LED, LED number 1. Thus, the first element of the epsilon1 vector is formed from the distance vector of the LED2, the second element of the vector from the distance vector of the LED3, and the third element from the distance vector is formed from the distance vector of the LED4. To complete the obtaining of the epsilon1, each of these vectors have to be multiplied by the k vector and the result divided by the Z0 coordinate previously obtained. Finally, the wanted vector is achieved. That is how it is done in the program:

$$\begin{aligned} \text{epsilon1}[0] &= 1/Z0 * (A[0][0]*k[0] + A[0][1]*k[1] + A[0][2]*k[2]); \\ \text{epsilon1}[1] &= 1/Z0 * (A[1][0]*k[0] + A[1][1]*k[1] + A[1][2]*k[2]); \\ \text{epsilon1}[2] &= 1/Z0 * (A[2][0]*k[0] + A[2][1]*k[1] + A[2][2]*k[2]); \end{aligned} \quad [18]$$

At this moment, epsilon0 and epsilon1 vectors are in the program. Now the epsilon0 is subtracted to the epsilon1, term by term, and done the absolute value of the subtraction, to check if the final results of each operation are greater or not than an error value previously defined.

$$|\text{epsilon1}[i] - \text{epsilon0}[i]| < \text{Error} \quad [19]$$

The selected value for this error is 0.1 and if the results of the subtractions are greater than the error value, the epsilon1 vector becomes the new epsilon0 vector. Thus, the process is repeated to obtain a new epsilon1 vector, from the estimation of the Xim and Yim vectors to the comparison step with the error value, until each subtracts between terms of the epsilons are lower than the error value. When that occurs, the translation vector and the rotation matrix can be built. As it was said previously, the translation vector is composed by the X and the Y coordinate of the reference object, which are the Xcenter[0] and Ycenter[0] variables of the program, and the Z0 coordinate obtained in the described process. The rotation matrix is formed by the row vectors i, j and k, and when the rotation matrix must be perfectly orthonormal, these vectors have to be renormalized, which is:

$$k' = k / |k| \quad j' = k' \times i \quad [20]$$

And this is obtained in the program in this way:

$$\text{mod} = \text{sqrt}(k[0]*k[0] + k[1]*k[1] + k[2]*k[2]); \quad [21]$$

$$\begin{aligned} \text{krot}[0] &= k[0]/\text{mod}; \\ \text{krot}[1] &= k[1]/\text{mod}; \\ \text{krot}[2] &= k[2]/\text{mod}; \end{aligned} \quad [22]$$

$$\begin{aligned} \text{jrot}[0] &= (\text{krot}[1] * i[2]) - (\text{krot}[2] * i[1]); \\ \text{jrot}[1] &= (\text{krot}[2] * i[0]) - (\text{krot}[0] * i[2]); \\ \text{jrot}[2] &= (\text{krot}[0] * i[1]) - (\text{krot}[1] * i[0]); \end{aligned} \quad [23]$$

In this manner, i vector is the first row of the rotation matrix, jrot vector is the second row and the krot vector the third row of the matrix.

5.6 Movement of the pointer

Once the POSIT algorithm is done and the rotation matrix composed by the three vectors i , j and k , they have to be translated into movement of the pointer of the mouse, depending on where the camera is pointing at. When finally that goal is achieved, the main objective of this project will be reached, built a head tracking system.

To start with the program, there is the same initialization part as the one was in the joystick program, because the USB port is going to act as a mouse. So it starts with this initialization part of the USB and the different handlers, and continues with the UART3 initialization and the code described for the configuration of the camera and the collect and store of data from the camera. After that comes the POSIT algorithm, as it is described in the previous point, and when the rotation matrix is obtained, it is used to move the mouse.

First of all, it is important to understand how the mouse works. In the descriptor, the movement of the mouse is changed from relative to absolute, because it is wanted to move the pointer where the user is looking at in the set, extrapolated it to the screen. After that, the structure `MouseInputReport` is used, like in the joystick program, to check how the pointer moves along the screen. Finally it is realized that, with the present descriptor, the pointer moves in the screen from 0 to 127 in the X axis and from 0 to 127 in the Y axis, with both 0s in the upper left corner.

To move the pointer, different proves are done with the vectors of the rotation matrix. All the components of the matrix have a range between -1 and 1, so they can be negative, and the maximum absolute valor is 1. Different pairs of components of the same vectors are tried to move the pointer, one for the X axis of the pointer and one for the Y axis. To translate these components into coordinates, it is needed to obtain the absolute value of the component and multiply it by 127, to get a coordinate according to the ones used in the movement of the mouse as have been seen previously. Finally, two components from the vector `krot` are taken, the first component (`krot[0]`) of the vector for the movement in the X axis and the third component (`krot[2]`) for the movement in the Y axis. These are the components from which the absolute value is taken and multiplied by 127. When the camera is moved from down to up, the cursor moves from up to down, so is necessary to subtract from 127 the obtained value treating the `krot[2]`, so the movement will be the correct one.

This way of solve the problem of the movement of the cursor works in one part of the screen, but sometimes it does not work for the entire screen. Different solutions have been used but none of them have improved the system, so the final block for the movement of the pointer of the mouse is the following:

```
vax = sqrt(krot[0]*krot[0]);  
vay = sqrt(krot[2]*krot[2]);
```

```
MouseInputReport.bX = vax*127;  
MouseInputReport.bY = (127 - vay*127);
```

Vax and vay are float variables where the absolute valor of the components of the vector are stored, and they are variables that are multiplied by 127.

6 Summary and Conclusions

Once the project is finished, some conclusions are obtained from the process of programming and the final obtained program and its functioning.

First of all, there is an unexplained problem commonly at the time of debug the LPC1758 with the Eclipse program. When the eStick2 is connected to the pc and the LPC1758 is tried to be debugged, sometimes it did not work and it is necessary to plug and unplug until it worked, or simply is needed to switch off the computer and start it again. That problem slows down a lot the programming of the software, because it cost a lot to connect with the debugger to check the code. It will be important to discover the origin of this problem to avoid it in the future.

The part of the USB connection was not so difficult and can be easily done following the user manual of the LPC1758. The manual always is a very good help and it had to be followed during all the programming. Previous programs are done to know how the connection worked, and finally adapt them to the program that wanted to build. So it was good to take previous little steps before facing the main problem. Most of the problems came with the programming of the camera. The first datasheet was not complete, to configure well the camera or ranges that each registers can be set, so the first configuration that could be done was not so good. Finally, with the second datasheet, there was a better idea about how to set the registers and, doing different test, it is concluded that the Gain1 and Gain2 registers of the camera have to be set to 15 and 0 respectively. But then came the part of data reception from the camera, where strange things with the value of the X and Y coordinates of the objects are discovered. They supposed to be between 0 and 1024 the X coordinates and between 0 and 768 the Y, but sometimes higher values appeared. A sweep is done with a light to discover what happened and finally the problem with the 8th bit of the variable is figured out, and it is solved before starting with the POSIT algorithm. Another problem that appeared is that the first and second blocks of data taken from the camera had strange values that confused the process that relate each object captured by the camera with each of the LEDs in the set, so this process and the POSIT algorithm are started after two buffer filling.

The implementation of the POSIT algorithm was easily done following the instructions in the paper of DeMenthon and Davis, and then the movement of the mouse is done with the obtained k vector from the POSIT. The movement of the cursor cannot be done properly in the entire screen. The causes can be the problems with the reception by the camera of the four LEDs and their later treatment, the obtaining of erroneous data, possible errors in the sending of the data from the camera to the LPC or the implementation of the movement code.

As conclusion can be said that with these components, the head tracking system cannot work well for the wanted objective. The LPC1758 is fast enough to receive the data from the camera, process it and send the mouse's pointer movement to the computer in a short time, but the problems come with the set of LEDs and the camera.

As it was seen in the realized tests with different gains and distances between the set and the camera, the longest distance that it can go is around 20 cm, which is so close to the screen of the pc, and it works in a narrow range of distances of more or less 10cm. If the experts are attended, they said that the eyes have to be between 40 and 60cm from the screen, which is quite far than the distance that the camera can give to us for a proper operation. So the position that the user has to take to use the system is not correct, and probably the solution will be worse than the problem. Apart from that, the program does not work well, there are parts in the screen where the cursor cannot follow the movement of the camera. There are several factors that can affect to that, like the mentioned problems to capture the LEDs, errors in transmitting or receiving and problems in the code, so the program cannot be used well even in a short distance.

The POSIT algorithm as is described in the “Model-based object pose in 25 lines of code” paper works perfectly integrated in the program of head tracking system.

The final idea is that is possible to build a head tracking system with some of the components, but it will be desirable to select other devices or amend them in order to improve the system and make it helpful and usable by the destination users; people with disabilities.

7 Future lines

It was said that the program works well, but it is needed more distance between the sensor and the LEDs, so the camera or the excitation source of the sensor of the camera can be changed. In the SET of LEDs, one possible solution is to put together more than one LED to simulate only one of the objects needed for the POSIT algorithm. A bunch of LEDs can be put in the positions of the set where now there is only one LED, to try to increase the power of it so the camera can capture it at a farther distance than the actual one. Another type of infrared light transmitter can be selected too, directive and with more power, but provably they will be more expensive than the LEDs.

In the case of the camera, the different registers have been changed and the best ones are selected. Changing the LEDs, the camera probably works better, but also can be tried the actual disposition of the system with a different camera of the PAC7001.

With the code, it can be studied to be improved, as well as the POSIT algorithm, which can be optimized. There are different possibilities of doing the main program too. The translation of the matrix obtained in the POSIT algorithm into the movement of the pointer of the mouse can also be optimized and done in a different way.

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A: LPC17xx Microcontrollers User Manual.

This appendix contains the direction for the LPC17xx User Manual, which is followed during all the programming of the LPC1758 and the development of the head tracking system. The User Manual can be localized in the website of the NXP Company:
http://www.nxp.com/documents/user_manual/UM10360.pdf

B: POSIT Algorithm

This appendix contains the direction to the paper of Daniel f. DeMenthon and Larry S. Davis “Model-Based Object Pose in 25 Lines of Code”, which is followed to obtain the pose of the camera with respect to the LEDs and translate it into movement of the mouse:
<http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=347E01840E649BC0FCB8E22DFB228873?doi=10.1.1.65.306&rep=rep1&type=pdf>

